

CERES Cloud Properties: Ed4, SNPP

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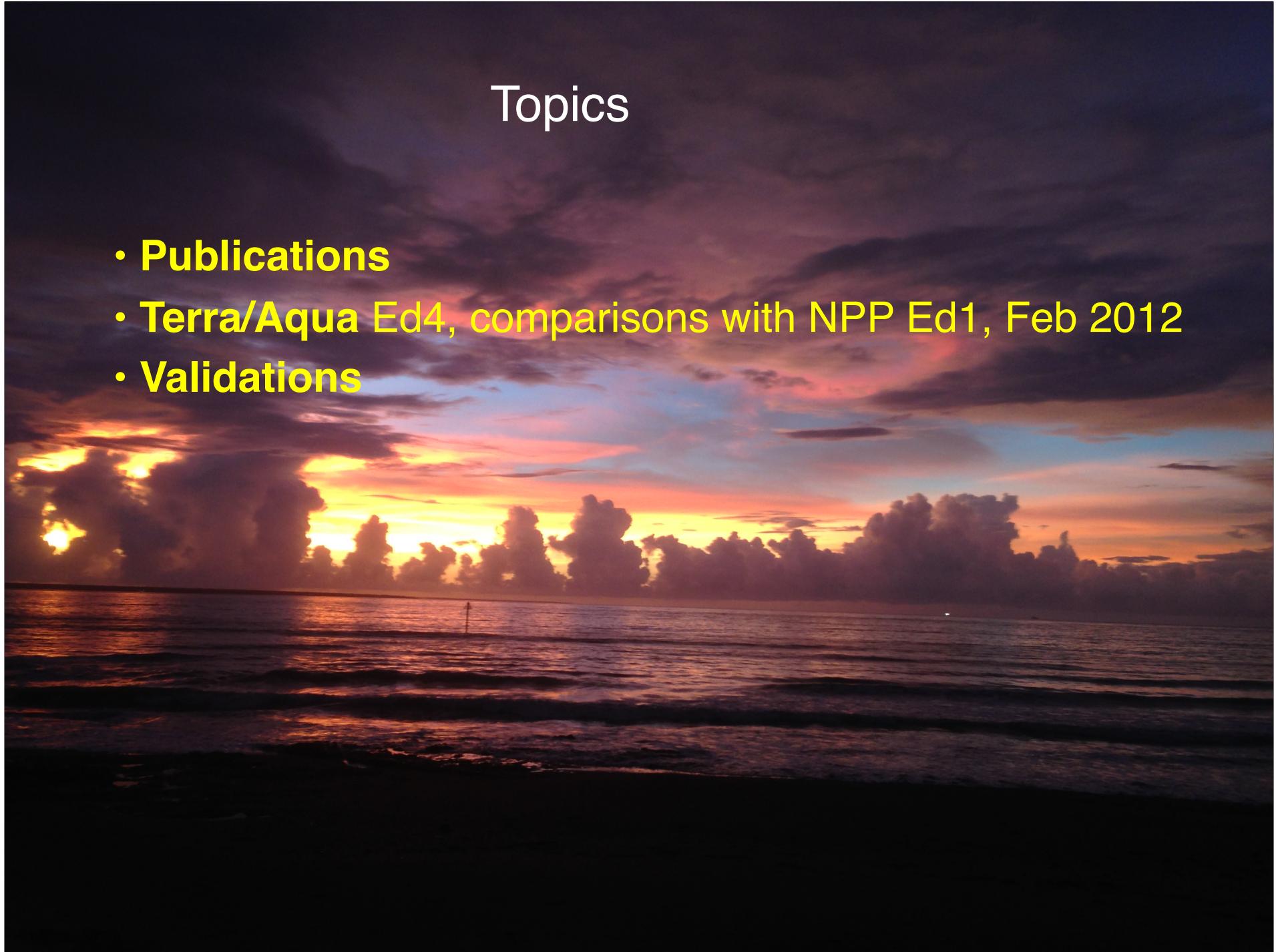


CERES Science Team Meeting, Newport News, VA, 22-24 April 2014



Topics

- Publications
- Terra/Aqua Ed4, comparisons with NPP Ed1, Feb 2012
- Validations



Update of CERES Cloud-related Papers since Oct 2013

Edition-2 related

Painemal, D., S. Kato, and P. Minnis, 2014: Biomass burning and the dual microphysical behavior of boundary layer clouds in the southeast Atlantic. Submitted, *J. Geophys. Res.*

Stanfield, R. E., X. Dong, B. Xi, A. Kennedy, A. D. Del Genio, P. Minnis, and J. Jiang, 2014: Assessment of NASA GISS CMIP5 and post-CMIP5 simulated clouds and TOA radiation budgets using satellite observations. Part I: Cloud fraction and properties. *J. Climate*, accepted.

Stanfield, R. E., X. Dong, B. Xi, A. D. Del Genio, P. Minnis, and J. Jiang, 2014: Assessment of NASA GISS CMIP5 and post-CMIP5 simulated clouds and TOA radiation budgets using satellite observations. Part II: TOA radiation budget and CREs. *J. Climate*, submitted.

Hamann, U., A. Walther, L. Bugliaro, M. Derrien, P. Francis, A. Heidinger, H. Le Gleau, M. Lockhoff, H. J. Lutz, P. Minnis, R. Palikonda, R. Preusker, J. Sauli, M. Stengel, S. Platnick, P. Watts, G. Wind, B. Baum, R. Bennartz, R. Roebeling, A. Thoss, and J. F. Meirink, 2014: Remote sensing of cloud top height from SEVIRI: Analysis of eleven current retrieval algorithms. Submitted, *Atmos. Meas. Tech.*

Edition-4 related

Sun-Mack, S., P. Minnis, Y. Chen, S. Kato, Y. Yi, S. Gibson, P. W. Heck, and D. Winker, 2014: Global cloudy boundary layer apparent lapse rates determined from CALIPSO and MODIS data. *J. Appl. Meteorol. Climatol.*

Xi, B., X. Dong, P. Minnis, and S. Sun-Mack, 2014: Validation of CERES-MODIS Edition 4 marine boundary layer cloud properties using DOE ARM AMF measurements at the Azores. *J. Geophys. Res.*, submitted.



MODIS Processing Status

- Ed2 processing
 - *Aqua: through June 2013, will continue until ED4 ADMs completed*
 - *Terra: through June 2013, will continue until Ed4 ADMs completed*
- Ed4 Beta-2, based on Coll. 5 data
 - *Aqua: through May 2005*
 - *Terra: through June 2005*



MODIS Edition-4 beta 2 Cautions

- Error in model look-up tables discovered
 - *mismatch between 0.65 and 3.8- μm optical depths*
 - *affects particle size and phase selection primarily*
 - *secondarily affects optical depth & cloud fraction*
 - *impacts ADM selection => fluxes*
- Thick ice cloud-top height correction not applied
 - *old Ed2 correction applied, $Z_{top} - Z_{eff} < 0.5 \text{ km}$*
 - *can be applied externally post facto, simple equation*
 - *affects cloud base and is inconsistent with VIIRS Ed1*
- CO2 thin ice cloud height correction to Z_{eff} may OE radiative height
 - *yields more accurate Z_{top}*
 - *produces underestimate of OLR wrt CERES in RTM computations*
- Error in parameterization of 1.24- μm reflectance
 - *affects R_e retrievals and tau over ice/snow*

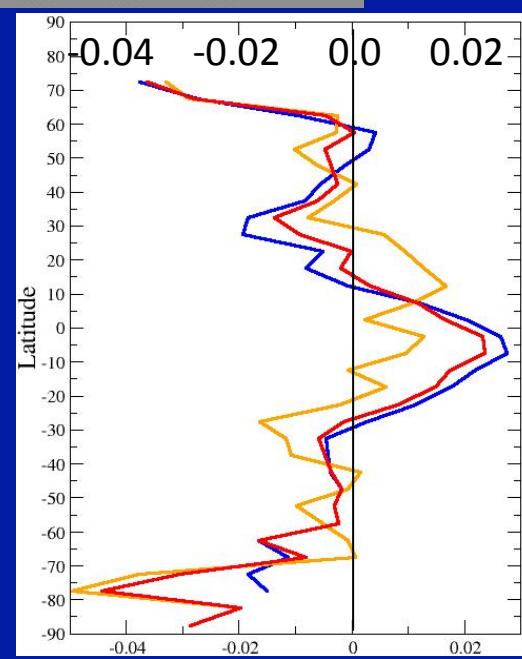
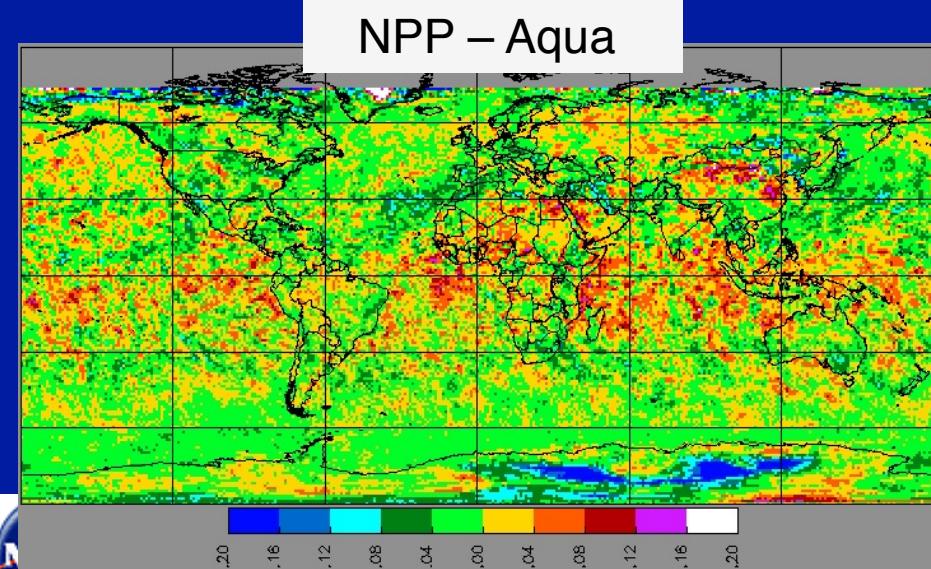
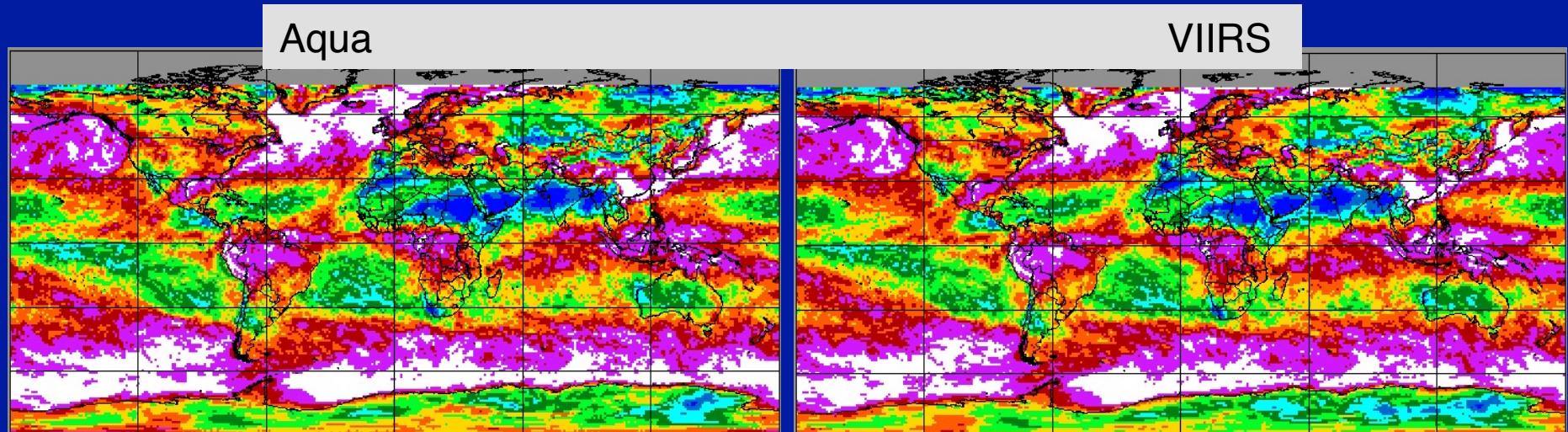


VIIRS Edition-1

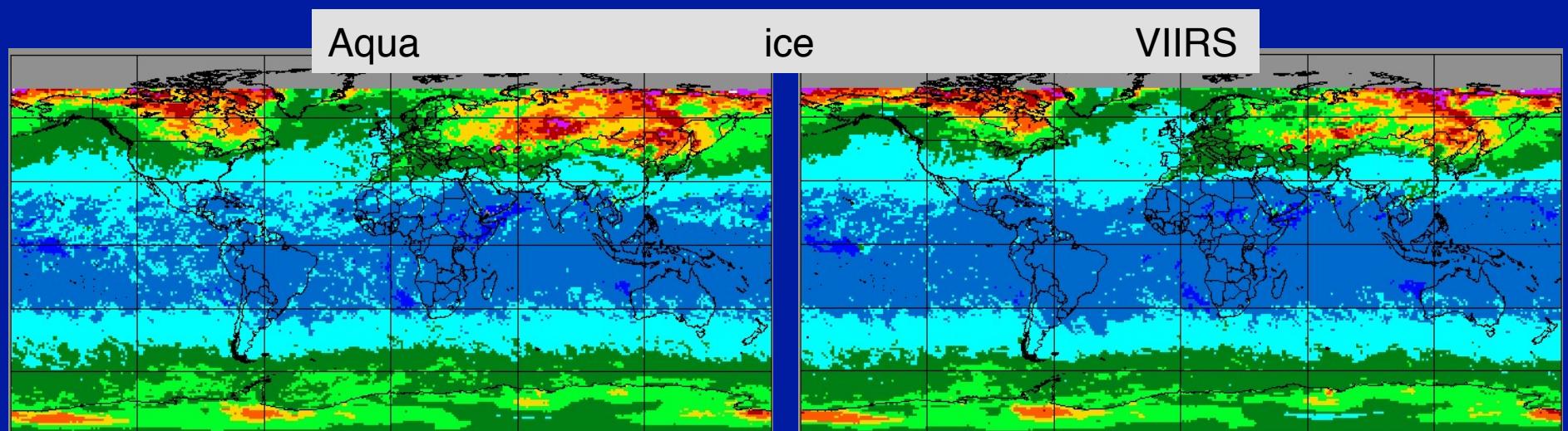
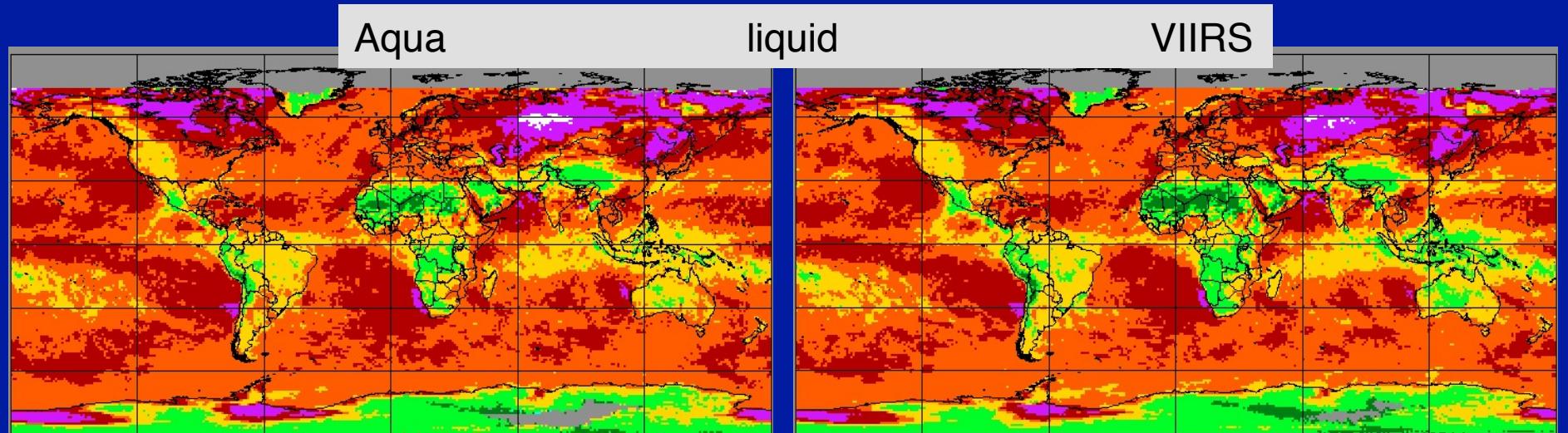
- Differences from Aqua Ed4
 - no WV or CO₂ channels
 - affects polar mask, ice cloud height & ML detection/retrieval
 - 11-12 μm BTD used in place of CO₂ channel (F-L Chang)
 - not a bad replacement
- Thick ice cloud-top height correction applied
 - no need for external post facto correction
 - affects cloud base and is inconsistent with Aqua Ed4
- Parameterization of 1.24-μm reflectance rewritten
 - Re retrievals and tau over ice/snow should be more reliable
- Uses revised water droplet model
 - 3.7-μm channel has better wavelength & solcon weighting (G Hong)



Total Cloud Amounts, Day, February 2012



Cloud Effective Pressure (hPa), Day, February 2012



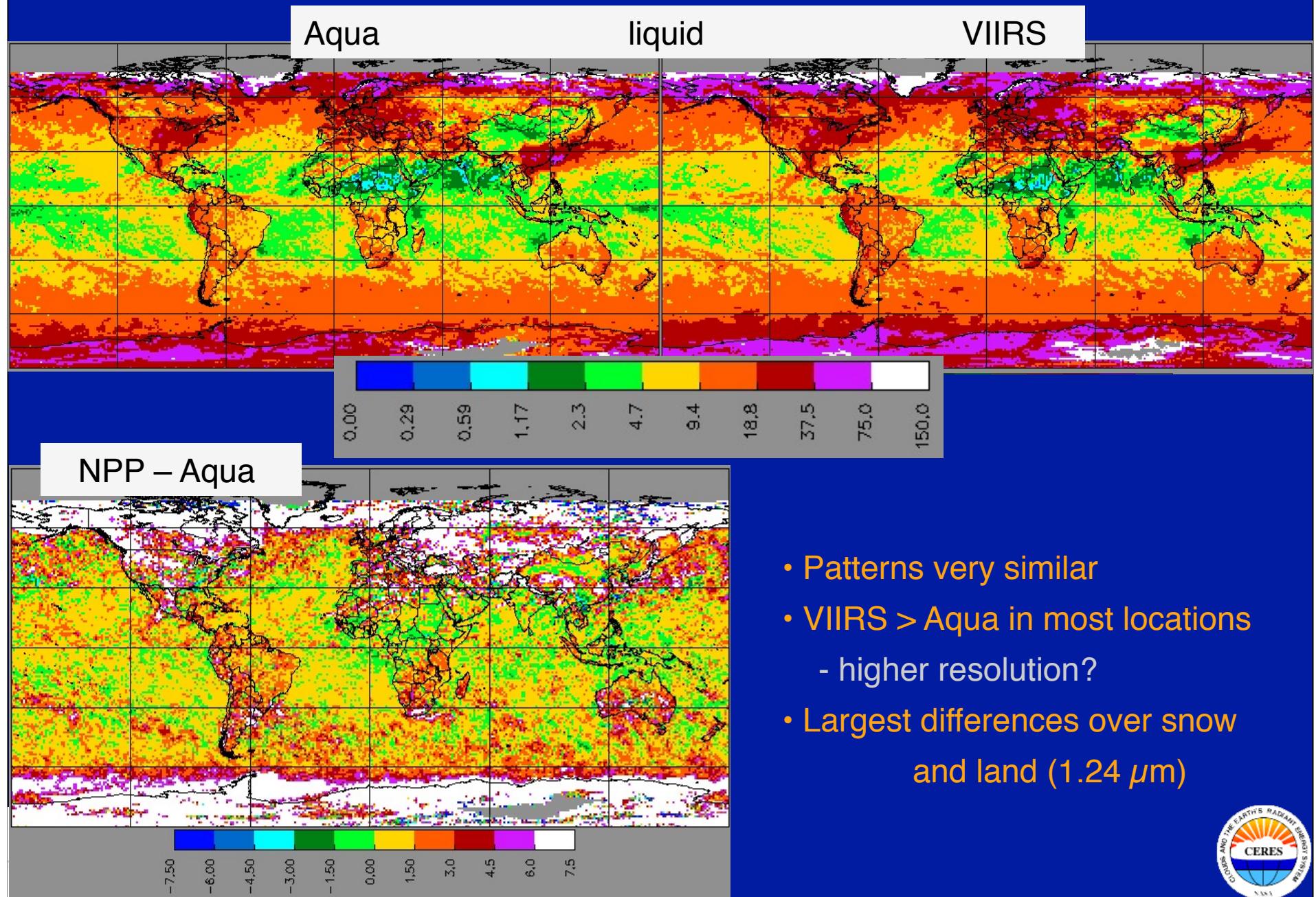
Mean Cloud Parameter Differences, February 2012

VIIRS - MODIS

		Day			Night		
Parameter	Global	NonPolar	Polar	Global	NonPolar	Polar	
CF	Water	0.004	0.000	0.031	-0.011	-0.010	
	Ice	-0.009	-0.001	-0.068	0.001	-0.002	
	Total	0.001	0.003	-0.021	-0.008	-0.011	
Zeff (km), Water	Water	0.17	0.18	0.14	0.09	0.08	
	Ice	0.36	0.37	0.26	0.17	0.12	
	Total	0.27	0.31	-0.01	0.13	0.08	
Peff (mb), Water	Water	-13.4	-13.4	-13.1	-7.8	-6.8	
	Ice	-18.6	-18.7	-17.4	-11.0	-8.1	
	Total	-15.5	-17.7	1.6	-10.6	-7.2	
Teff (K), Water	Water	-1.1	-1.1	-0.9	-0.5	-0.5	
	Ice	-2.4	-2.5	-1.5	-0.8	-0.5	
	Total	-1.8	-2.0	-0.2	-0.7	-0.4	

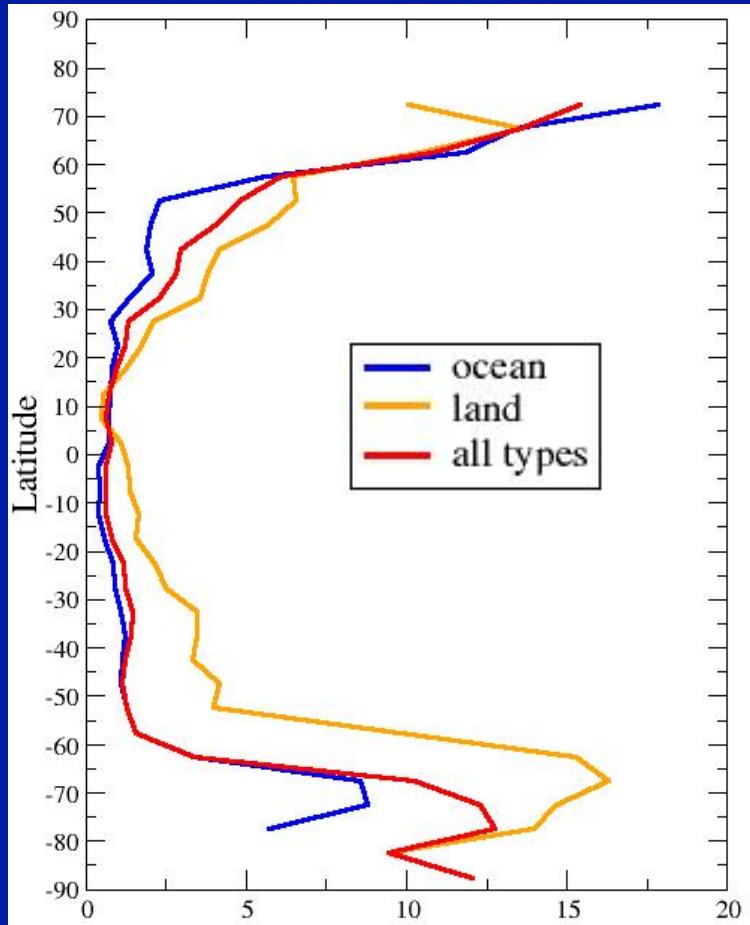


Mean Cloud Optical Depths, February 2012

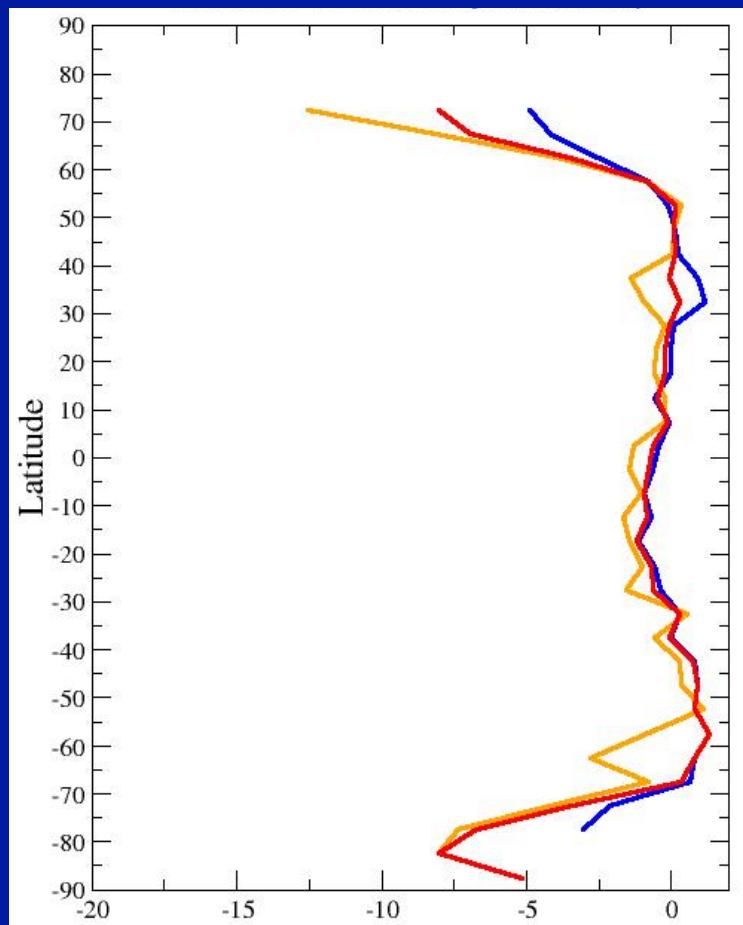


Zonal Mean Cloud Optical Depth Differences, February 2012 VIIRS - MODIS

Liquid



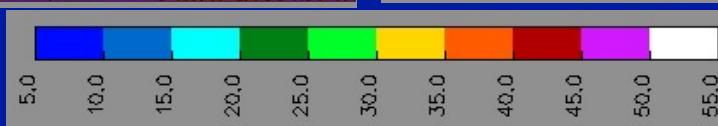
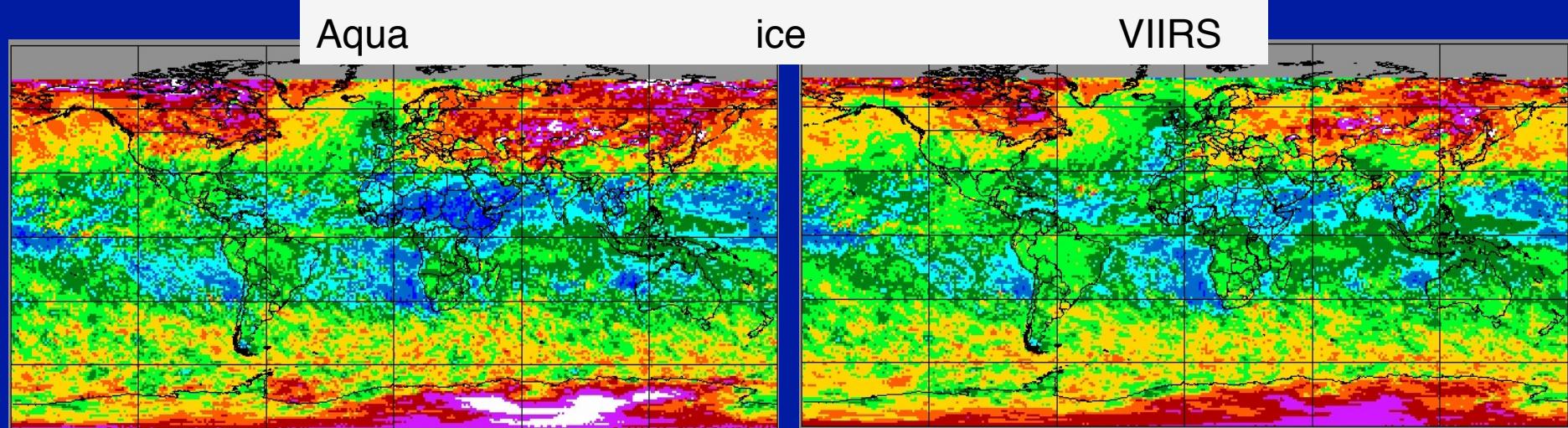
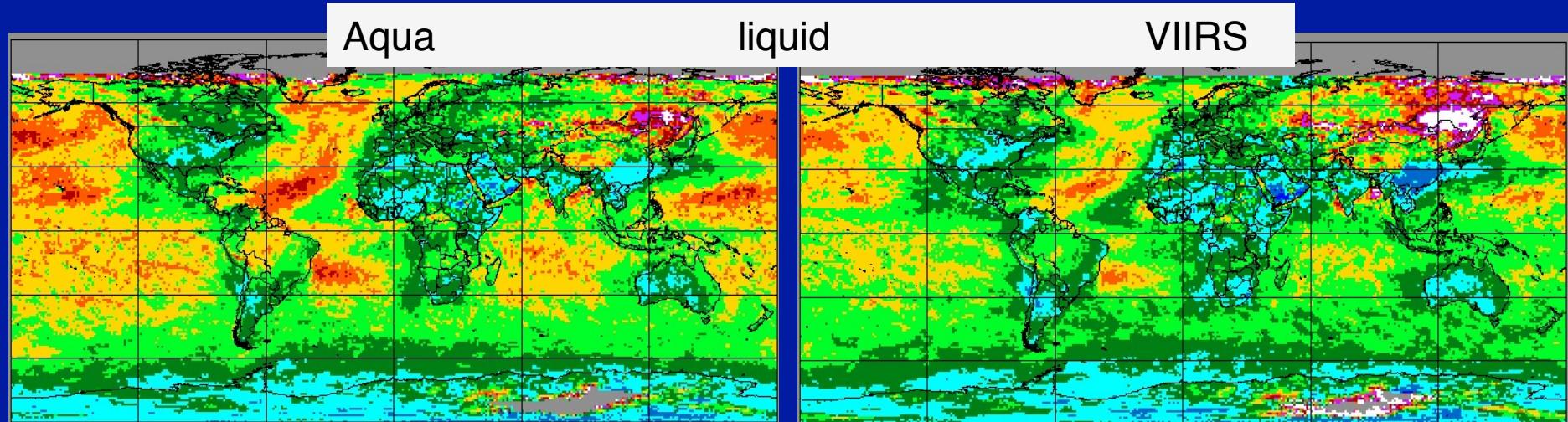
Ice



- VIIRS water cloud tau > Aqua everywhere, land especially
- VIIRS ice cloud tau slightly < Aqua in tropics, = in mid latitudes, much smaller in polar regions



Cloud Particle Effective Radius (μm), Day, February 2012



Mean Cloud Parameter Differences, February 2012

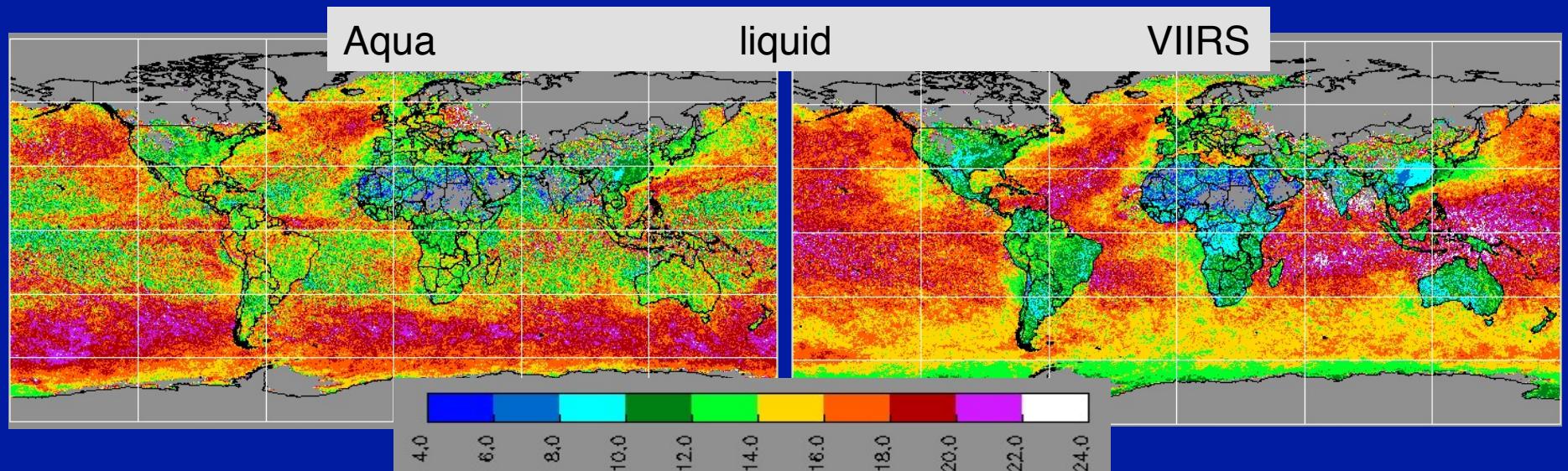
VIIRS - MODIS

		Day			Night		
Parameter		Global	Non Polar	Polar	Global	Non Polar	Polar
Tau	Water	2.61	1.56	10.55	-0.14	-0.18	0.15
	Ice	-0.59	-0.19	-3.62	-0.08	-0.03	-0.39
	Total	1.44	0.83	6.07	-0.19	-0.10	-0.79
Re (μm)	Water	-0.7	-0.9	0.3	-0.2	-0.3	0.3
	Ice	0.0	0.4	-2.4	-2.3	-2.6	-0.6
	Total	-1.0	-0.7	-3.6	-1.2	-1.4	0.1
LWP (gm^{-2})		37.6	15.1	207.0	3.3	-0.7	28.9
IWP (gm^{-2})		9.4	21.8	-84.3	7.1	8.0	1.2
TWP (gm^{-2})		21.3	14.1	76.1	2.6	3.2	-1.1

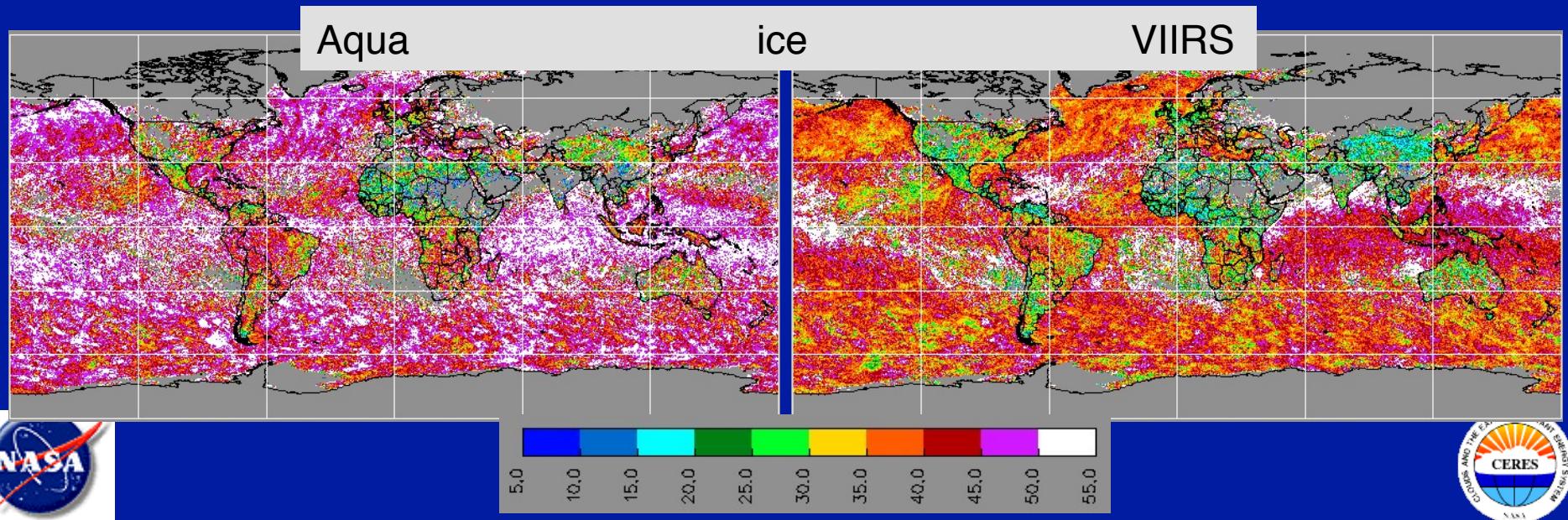
- VIIRS water cloud tau > Aqua everywhere, Re < Aqua Re
 - LWP > Aqua LWP
- VIIRS nonpolar ice cloud tau < Aqua, Re slightly > Aqua
 - IWP slightly > Aqua IWP



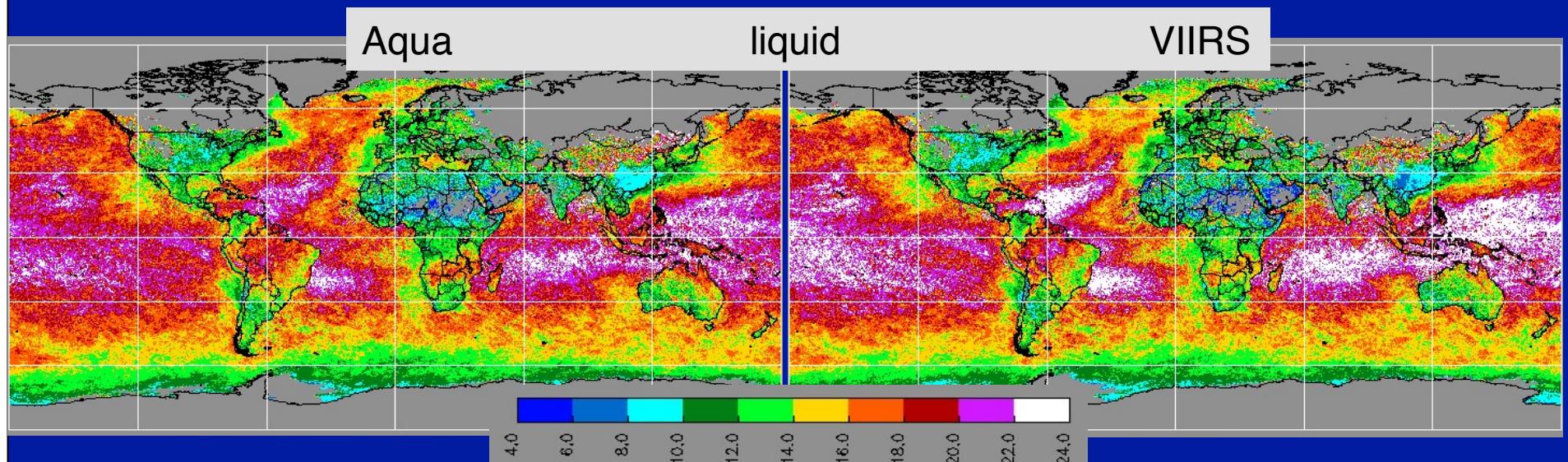
1.24- μm Cloud Particle Effective Radius (μm), Day, February 2012



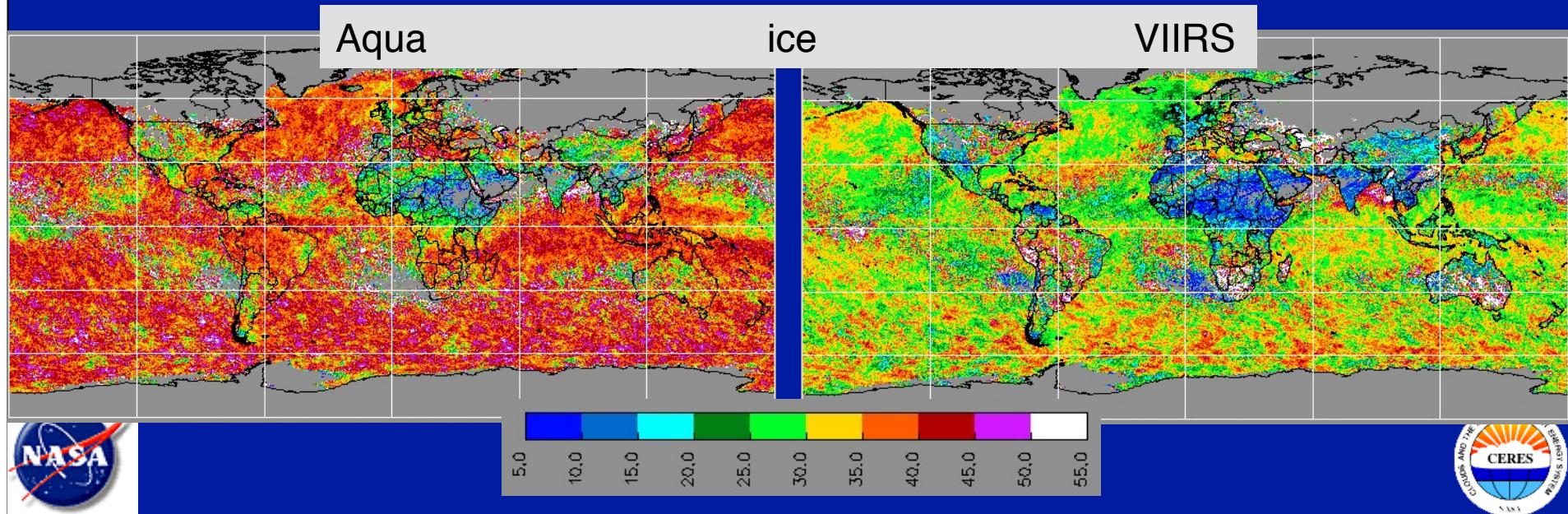
- Very little agreement between VIIRS and Aqua



1.6/2.1- μm Cloud Particle Effective Radius (μm), Day, February 2012

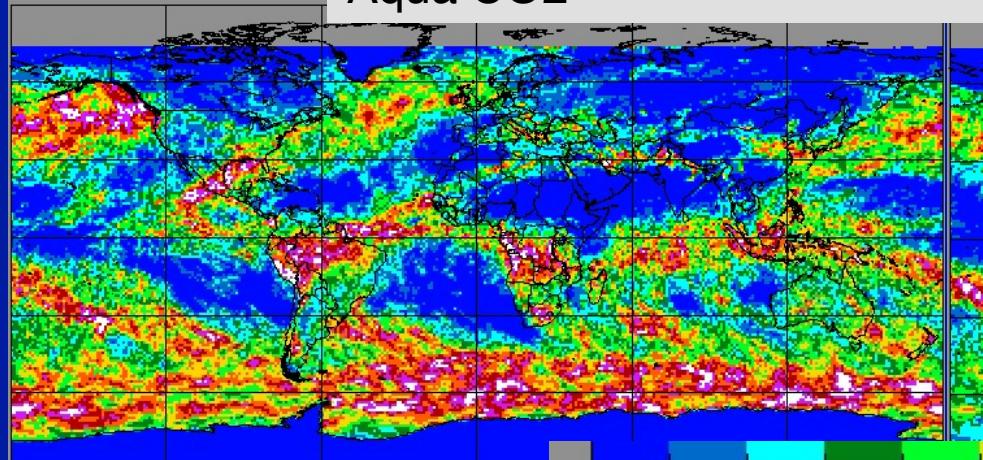


- Water clouds very similar, ice clouds different

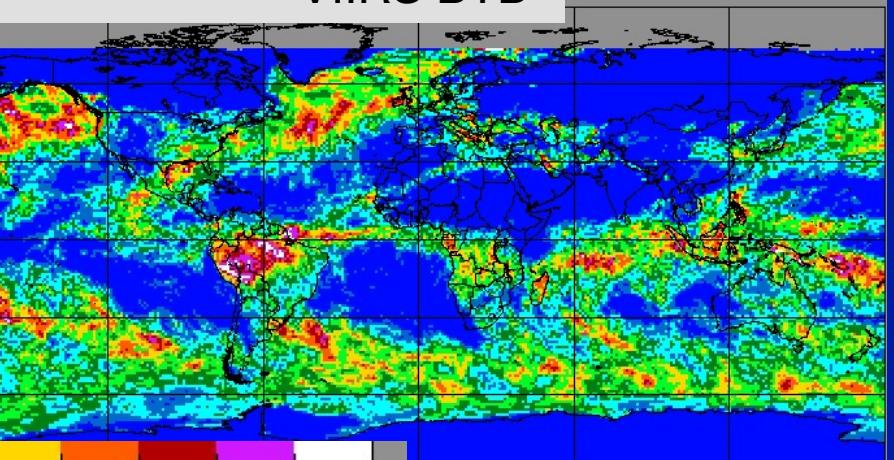


Multi-Layer Cloud Amounts, Day, February 2012

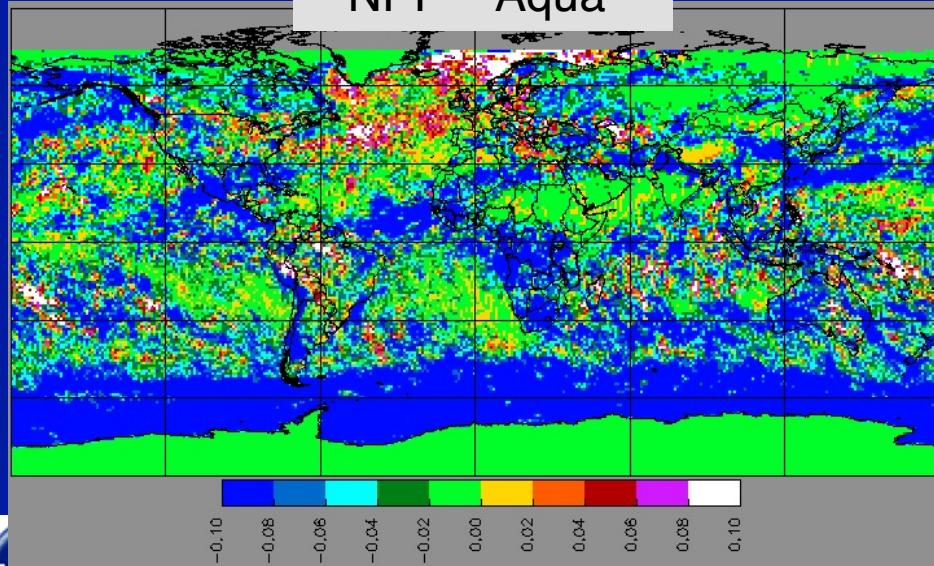
Aqua CO2



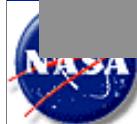
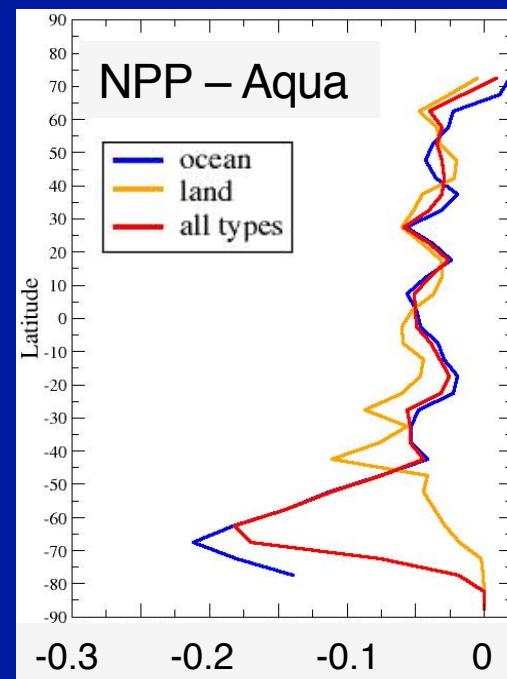
VIIRS BTD



NPP – Aqua



NPP – Aqua



Mean Multi-layer Cloud Parameter Differences, February 2012

VIIRS BTD – MODIS CO₂

Parameter	Day			Night		
	Global	Non Polar	Polar	Global	Non Polar	Polar
ML Amount	-0.050	-0.047	-0.075	-0.098	-0.095	-0.121
ML Fraction	-0.035	-0.031	-0.065	-0.073	-0.069	-0.098
UL Height (km)	0.98	1.02	0.72	1.41	1.57	0.28
UL Re (μm)	-0.2	-0.6	3.6	-5.5	-6.1	-0.6
UL Tau	-0.212	-0.204	-0.273	-0.335	-0.331	-0.363
LL Height (km)	-0.67	-0.72	-0.26	-0.71	-0.77	-0.26
LL Re (μm)	-0.1	-0.2	0.3	-0.9	-0.9	-0.5
Ztop (km)	0.92	0.97	0.59	1.36	1.43	0.90

- VIIRS BTD detects fewer ML clouds, especially over roaring 40-50°S
- VIIRS UL height ~ 1 km higher than CO₂ height
- VIIRS LL height ~0.7 km lower than CO₂ height
- VIIRS Re similar to MODIS, except at night



VALIDATION

- CALIPSO: Tau for thin ice, Ztop, phase, fraction
- SEAC4RS flights: Re, Ztop
- Satellite consistency: MODIS, VIIRS, AVHRR
- ARM surface obs, Azores: Ztop, Re, tau, LWP, Zbase



Aqua MODIS Ed-4 beta2 Comparison with CALIPSO

- Spatially/temporally matched cloud properties for 12 days
 - 10-12 Jul 2012
 - 15-17 Oct 2012
 - 15-17 Jan 2013
 - 17-19 Apr 2013
- CALIPSO data
 - Vertical Feature Mask (VFM): number of cloud layers, SL/ML identification, cloud phase, and layer opacity
 - 5-km Cloud Layers product: cloud altitudes, optical depths, and IWP
 - 333-m Cloud Layers product: low-cloud altitudes

H - Hit rate, fraction CALIPSO clouds detected

→ FC – fraction correct

FAR – false alarm rate

B – bias ratio

CSI – critical success index

HSS – Heidke skill score



Cloud Amount Comparison, Aqua Ed4 vs CALIPSO

12 days

	FRACTION CORRECT	NUMBER OF MATCHES
DAYTIME		
Nonpolar, Land, Snow-free	0.886	101448
Polar, Land, Snow-free	0.907	15888
Non-polar, Ocean, Ice-free	0.894	293679
Polar, Ocean, Ice-free	0.942	28999
Global, Snow/Ice-covered	0.868	119633
NIGHT		
Nonpolar, Land, Snow-free	0.873	97649
Polar, Land, Snow-free	0.870	13751
Nonpolar, Ocean, Ice-free	0.905	308185
Polar, Ocean, Ice-free	0.937	40803
Global, Snow/Ice-covered	0.787	204745



Overall global result for fraction correct, Day: 0.890, Night: 0.865
 Night much better for nonpolar areas ~0.9.



Cloud Fraction Comparison

Fraction Correct

Type	Aqua			VIIRS			AVHRR
	<u>Ocean</u>	<u>Land</u>	<u>All</u>	<u>Ocean</u>	<u>Land</u>	<u>All</u>	<u>All</u>
Global Day	0.92	0.87	0.89	0.91	0.86	0.88	0.86
Global night	0.91	0.78	0.86	0.85	0.77	0.83	0.83
Global Term			0.89			0.80	0.80
	<u>Day</u>	<u>Night</u>					
Tropics Day	0.88	0.85					
Midlat Day	0.92	0.87					
Polar Day	0.90	0.81					

- Ed4 mask more accurate than Ed2; Midlat best
- AVHRR & VIRS nearly as accurate Ed4, polar night worst
- Night land is also a source of cloud underestimation
- Including 80-km clouds reduces these numbers by ~0.02 to 0.03



Cloud Phase Comparison, Aqua Ed4 vs CALIPSO 12 days, only single-layered

	FRACTION CORRECT	Ice FAR	Water FAR	NUMBER OF MATCHES
DAYTIME				
Nonpolar, Land, Snow-free	0.936	0.005	0.193	21291
Polar, Land, Snow-free	0.943	0.009	0.109	3051
Nonpolar, Ocean, Ice-free	0.978	0.017	0.025	103682
Polar, Ocean, Ice-free	0.959	0.099	0.022	7906
Global, Snow/Ice-covered	0.926	0.074	0.073	22142
NIGHT				
Nonpolar, Land, Snow-free	0.914	0.023	0.289	22428
Polar, Land, Snow-free	0.915	0.050	0.151	2613
Nonpolar Ocean, Ice-free	0.947	0.069	0.042	98369
Polar Ocean, Ice-free	0.912	0.155	0.034	8448
Global, Snow/Ice-covered	0.876	0.126	0.116	38144



Cloud Phase Fraction Comparison

Fraction Correct: Single layer, pure phase only (~1/3 pixels)

Type	<u>FC</u>	Aqua	VIIRS		AVHRR	
		<u>Bal +W</u>	<u>FC</u>	<u>Bal +W</u>	<u>FC</u>	<u>Bal +W</u>
Global Day	0.96	0.012	0.98	0.001	0.92	0.006
Global night	0.93	-0.011	0.96	-0.005	0.89	0.010
Global Term	0.83	-0.103	0.87	-0.107	0.78	-0.191
	<u>Day</u>	<u>Night</u>				
Tropics	0.96	0.90				
Midlat	0.97	0.95				
Polar	0.94	0.86				

- Fairly well balanced phase selection
- terminator ($82^\circ < \text{SZA} < 89^\circ$) area yields too much ice cloud

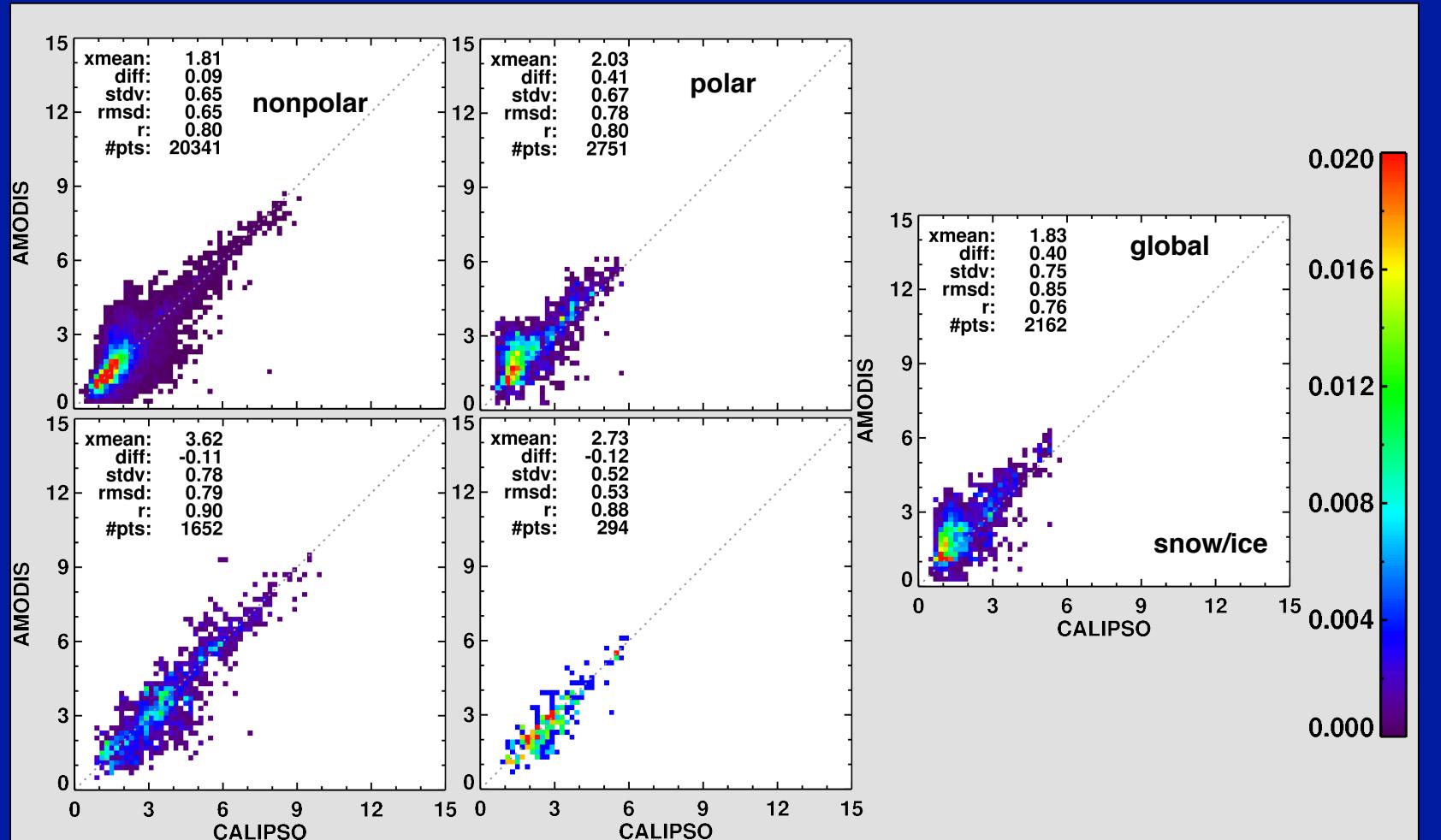


cloud top altitude

water phase, nighttime, opaque

ocean

land



- Mean non-polar thick water cloud tops within 100 m of CALIPSO
- Elsewhere, overestimate by 300-400 m



Cloud Height Difference, Aqua Ed4 - CALIPSO 12 days, only single-layered, Mean (std dev) in km

	Day		Night	
	Opaque	Nonopaque	Opaque	Non-opaque
Water				
Nonpolar Land, Snow-free	-0.14 (0.73)	-0.57 (1.25)	-0.11 (0.78)	-0.16 (0.80)
Polar Land, Snow-free	-0.18 (0.60)	-0.04 (0.87)	-0.12 (0.52)	-0.05 (1.12)
Nonpolar Ocean, Ice-free	-0.14 (0.70)	-0.01 (0.70)	0.09 (0.65)	0.23 (0.84)
Polar Ocean, Ice-free	0.03 (0.72)	0.10 (0.54)	0.41 (0.67)	0.39 (0.75)
Global Snow/Ice-covered	-0.05 (0.89)	0.17 (1.04)	0.40 (0.75)	0.54 (1.00)
Ice				
Nonpolar Land, Snow-free	-2.18 (1.48)	-1.63 (2.27)	-1.95 (1.40)	-0.32 (2.02)
Polar Land, Snow-free	-1.68 (1.29)	-1.22 (2.24)	-1.82 (1.13)	-1.26 (2.17)
Nonpolar Ocean, Ice-free	-2.38 (1.48)	-2.43 (2.79)	-2.09 (1.36)	-0.59 (1.95)
Polar Ocean, Ice-free	-1.54 (1.39)	-1.22 (2.32)	-0.79 (0.84)	-0.53 (1.54)
Global Snow/Ice-covered	-1.44 (1.41)	-3.04 (2.05)	-1.47 (1.42)	-1.51 (2.04)



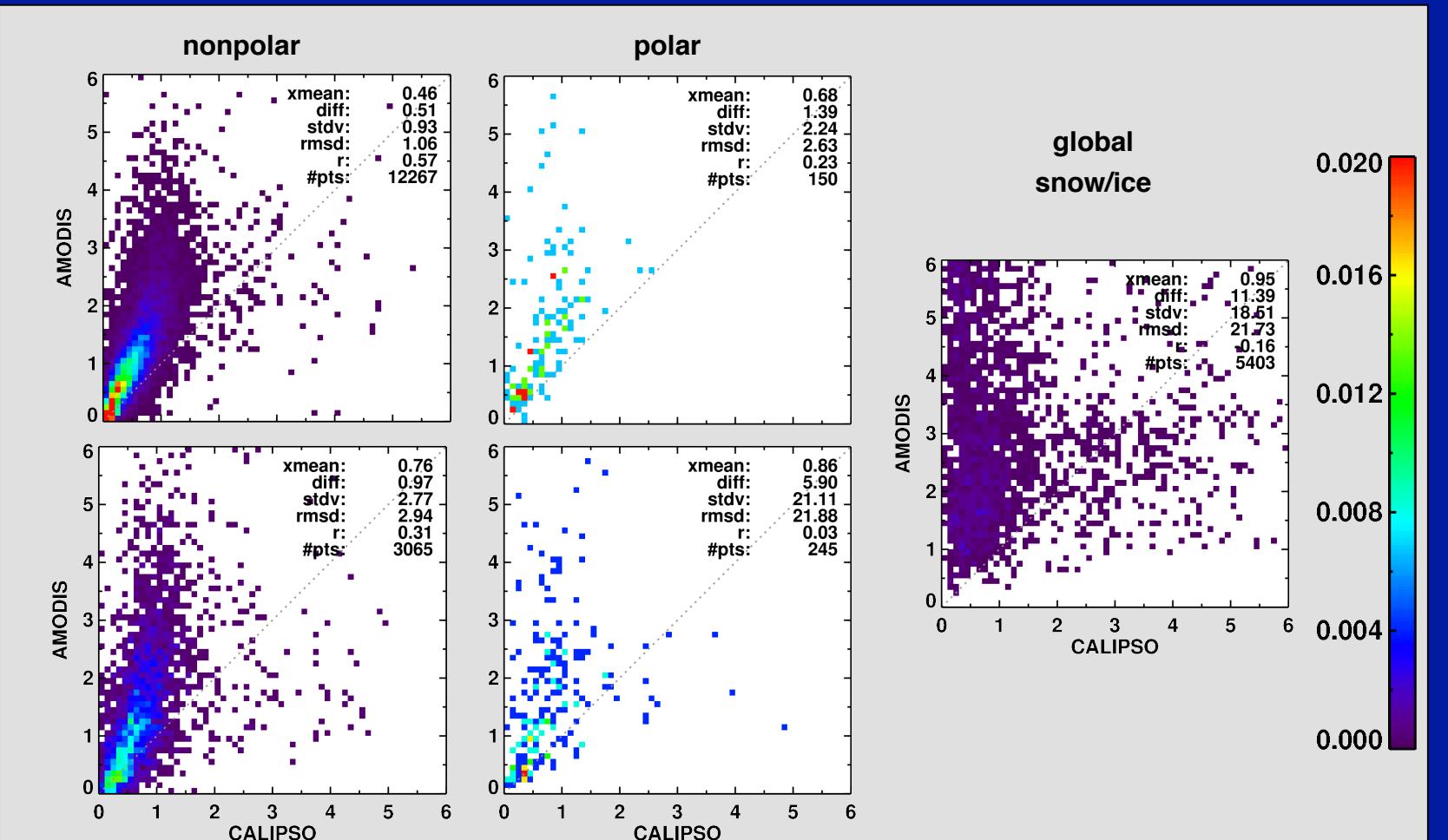
* Thick ice cloud top correction not applied, applying the correction post facto reduces biases to -0.16 (day) and 0.01 (night)



Ice cloud optical depth, daytime, non-opaque

ocean

land



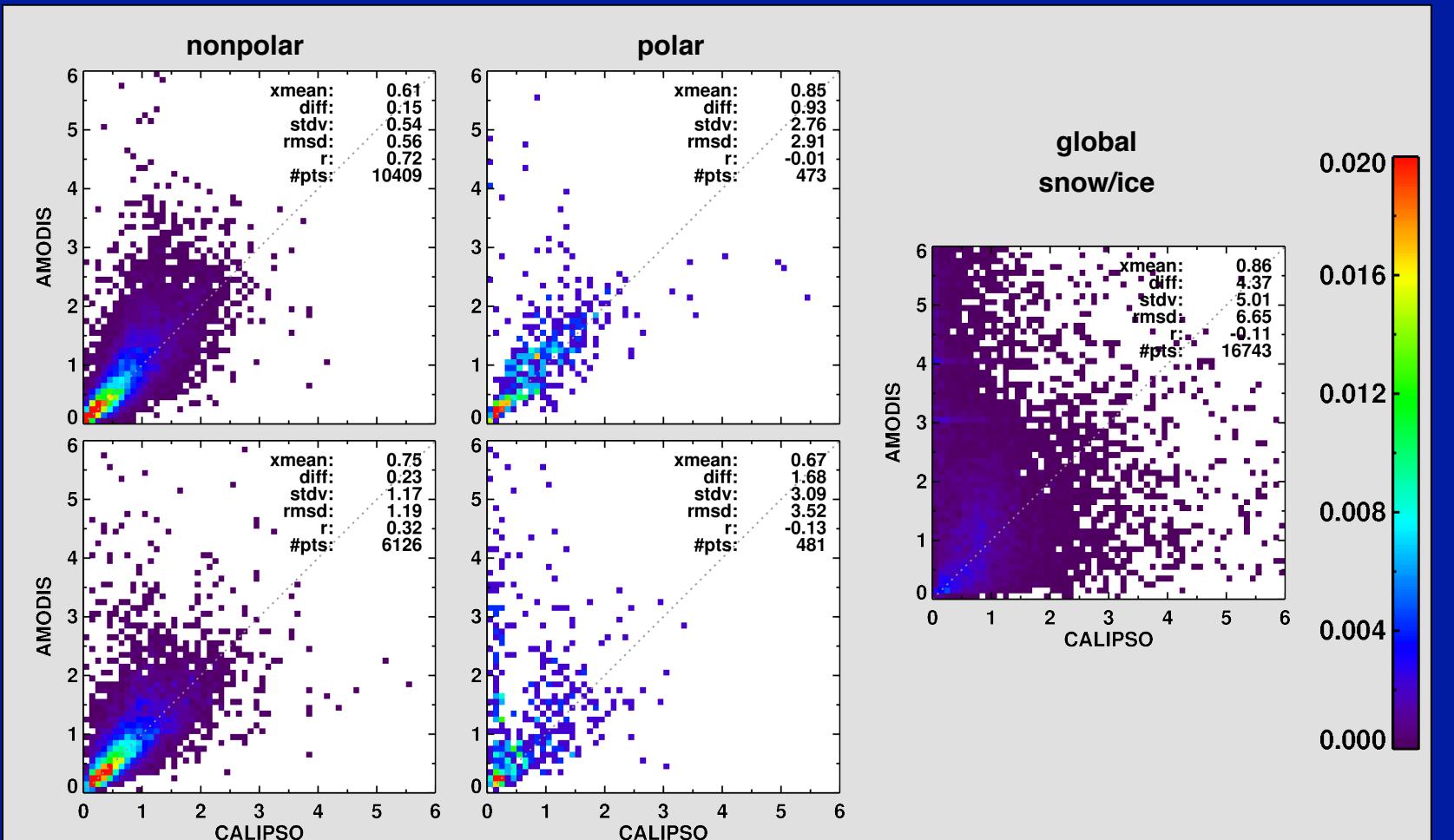
- Thin Ice clouds, $\tau(\text{MOD}) \sim 1.7 \tau(\text{CAL})$
- Not worth much over snow



Ice cloud optical depth, night, non-opaque

ocean

land



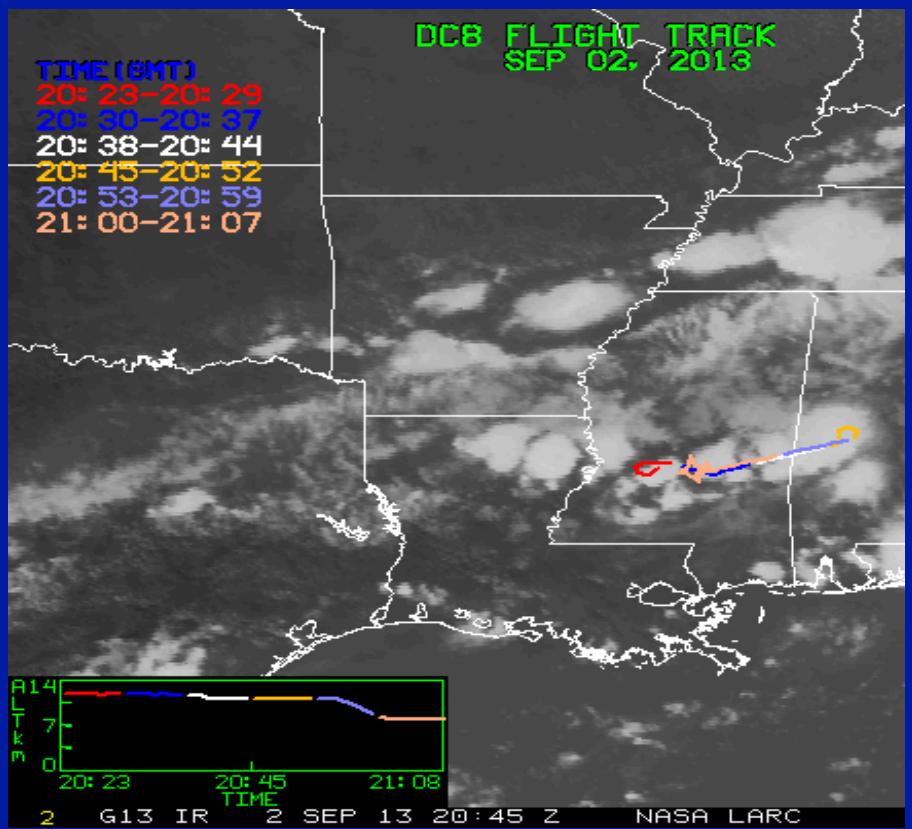
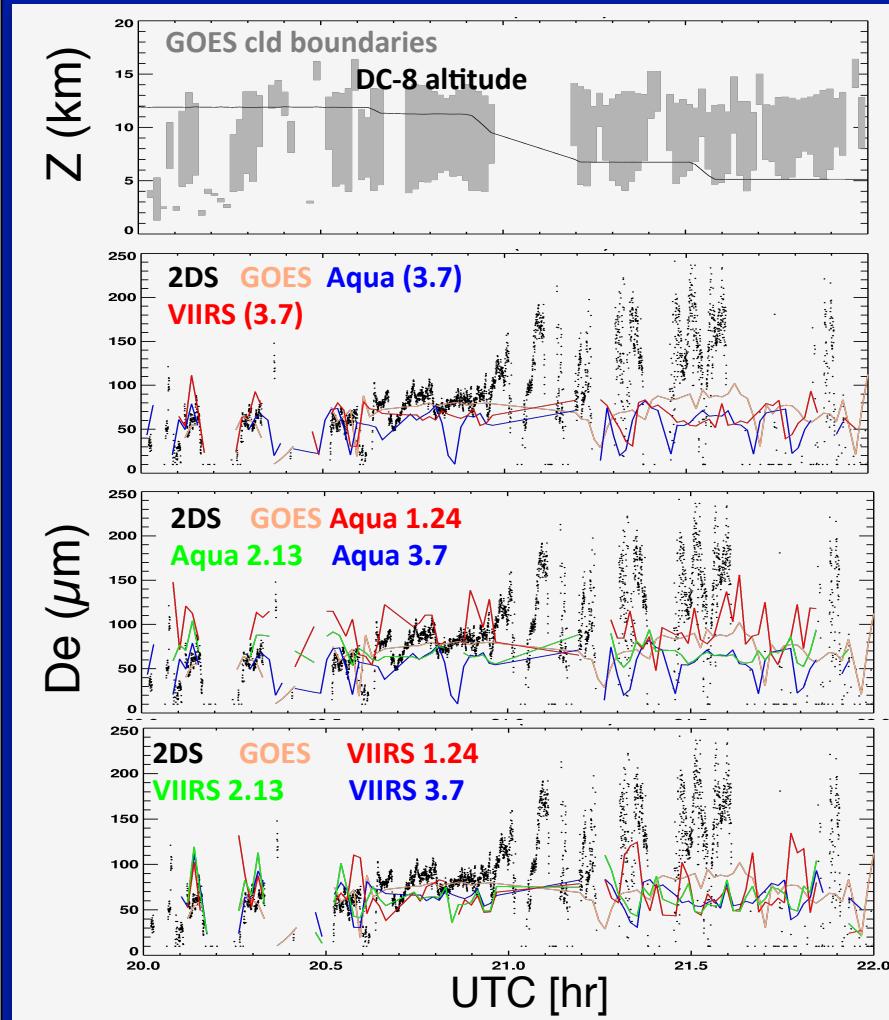
- Most thin Ice clouds, $\tau(\text{MOD}) \sim 1.0 \tau(\text{CAL})$
- Too much uncertainty over snow



Initial Validation Studies Using SEAC4RS Data

DC-8 Ice Particle Effective Diameter Comparisons

September 2, 20 – 22 UTC



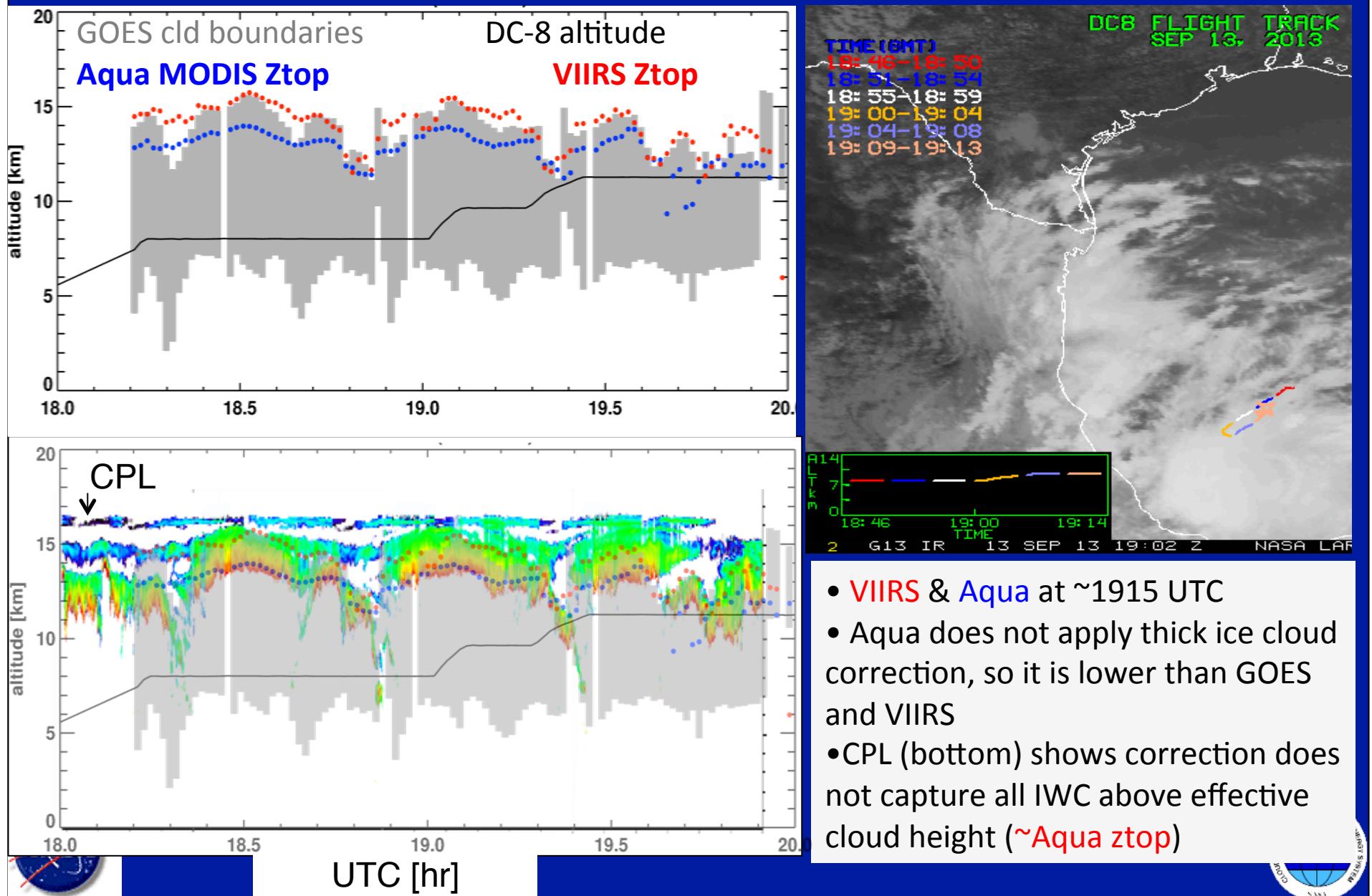
- Aqua and VIIRS overpasses at ~1930 UTC
- Best agreement for 3.7 μm near cloud top

- 1.24 μm best deeper in cloud, not much difference between 2.13 & 3.7



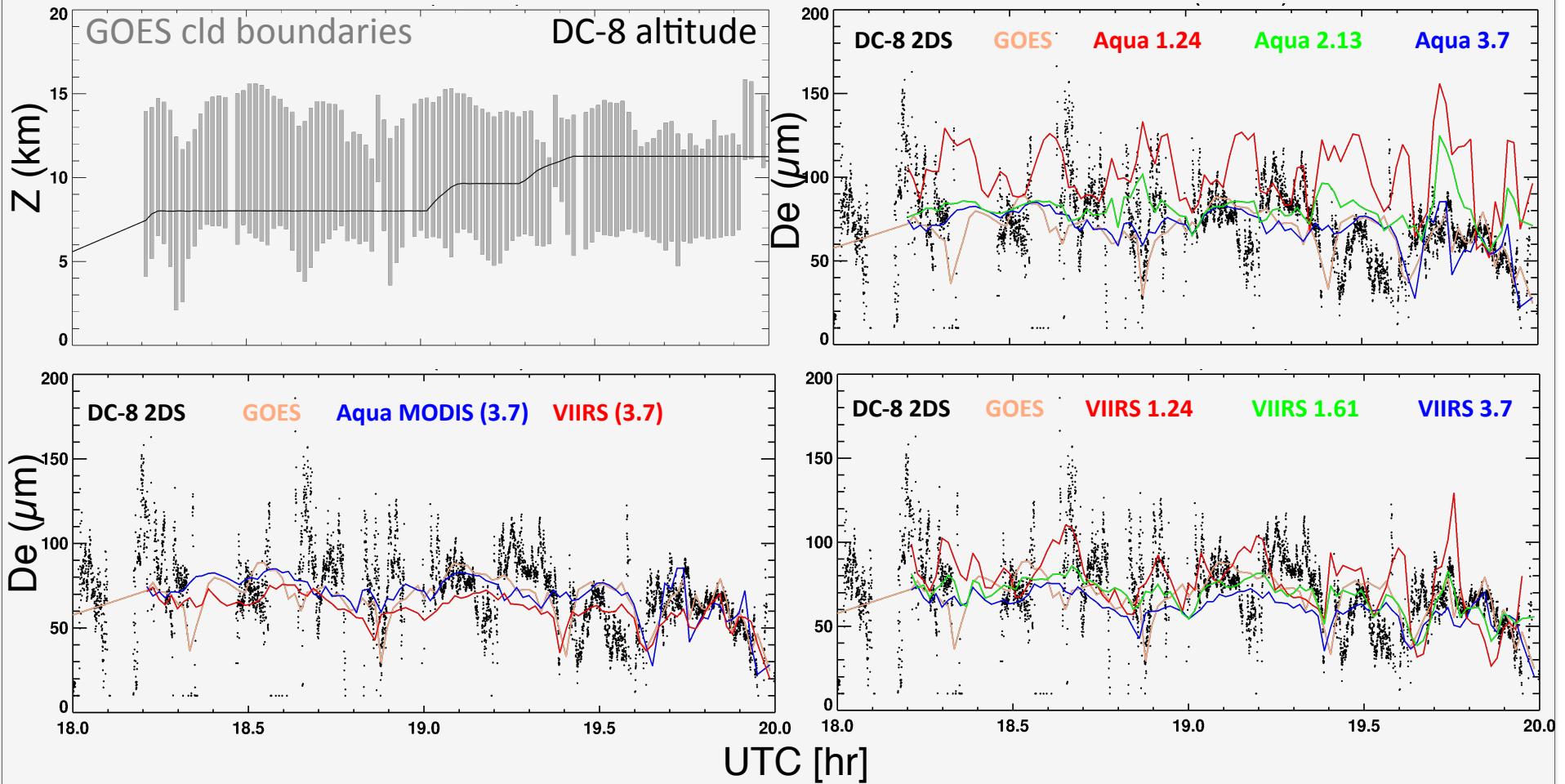
Cloud Heights Along the DC-8 Flight Track

September 13, 18 – 20 UTC



DC-8 Ice Particle Effective Diameter Comparisons

September 13, 18 – 20 UTC



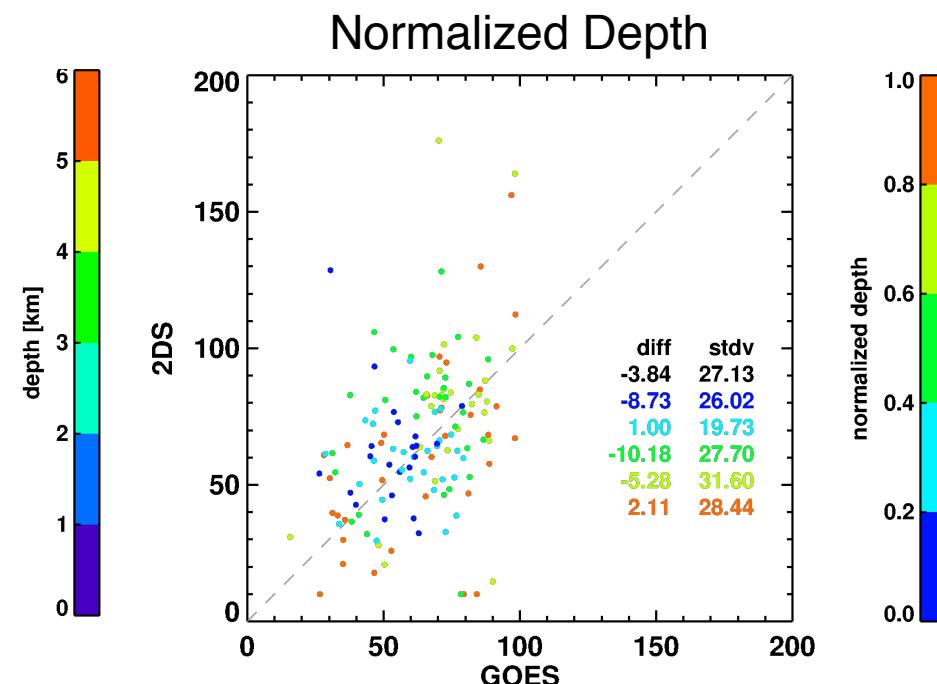
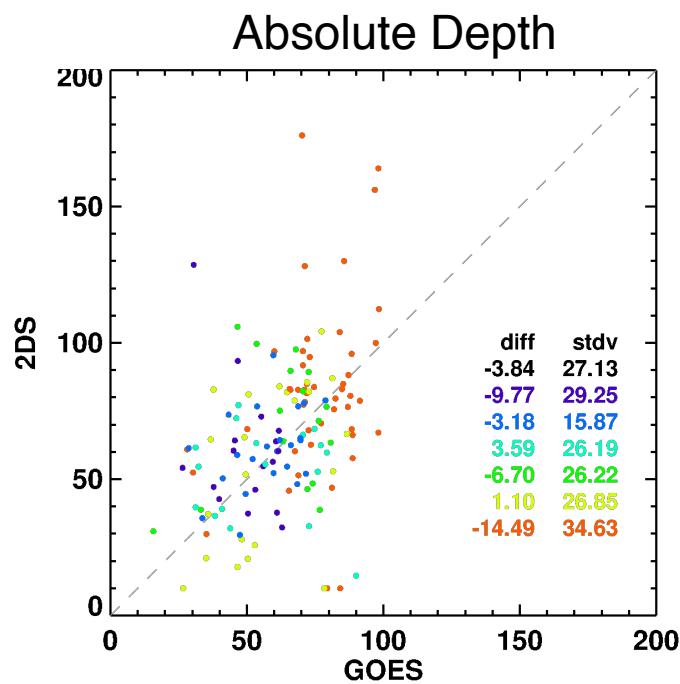
- GOES, Aqua, VIIRS all consistent at $\sim 3.8 \mu\text{m}$; best agreement near cloud top
- Better agreement near cloud base and middle with other channels: 1.2, 1.6, and $2.1 \mu\text{m}$



DC-8 Ice Particle Effective Diameter Comparisons

September 13, 16 -22 UTC

- results shown for entire flight on 9/13, color-coded by...
 - absolute depth below cloud top (left; 0.0 = cloud top)
 - normalized depth below cloud top (right; 0.0 = cloud top, 1.0 = cloud base)
 - GOES 3.9- μ m retrievals used to define cloud top and base



- Agreement, on average, occurs \sim 2.5 km from top for this day
 - translates to a normalized depth of \sim 0.4 from cloud top as determined by GOES



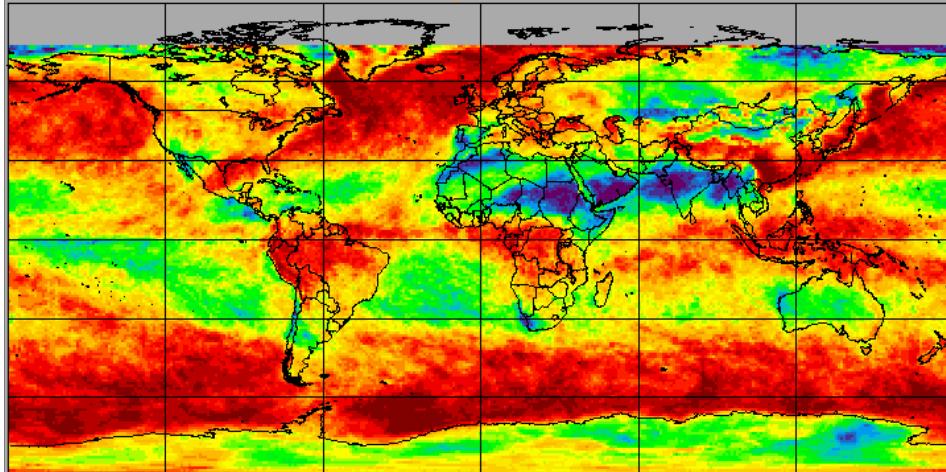
SEAC4RS Comparison Summary

- Initial comparisons performed with some aircraft data
 - cloud heights track well, perhaps a bit low
 - 3.7 – 3.9 μm retrievals of De match well with flight ~2 km below cloud top
 - 1.6 & 2.1- μm De generally larger & match better deeper in cloud
 - 1.24- μm De largest and matches better near bottom of cloud in thick clouds
 - Aqua 1.24- μm noisier than VIIRS retrieval
 - Good consistency among Aqua, VIIRS, and GOES

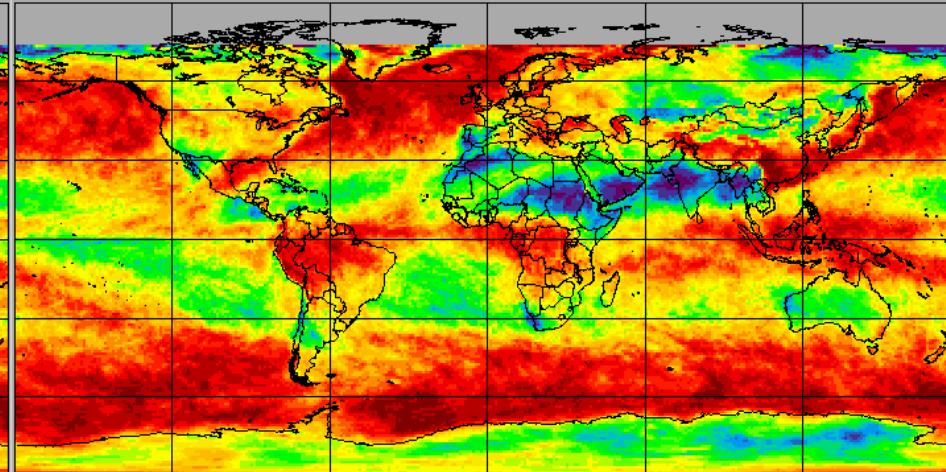


Mean Cloud Fractions, Day, February 2012

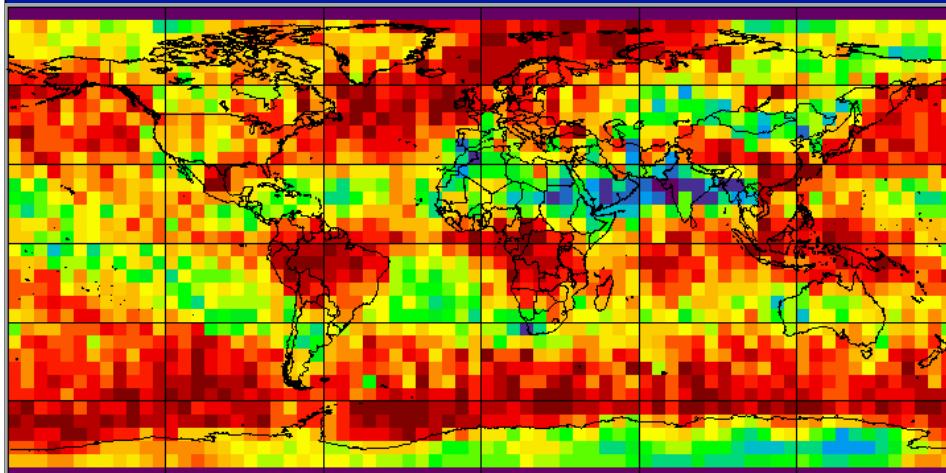
Aqua



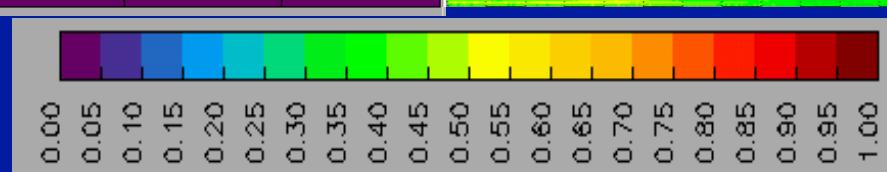
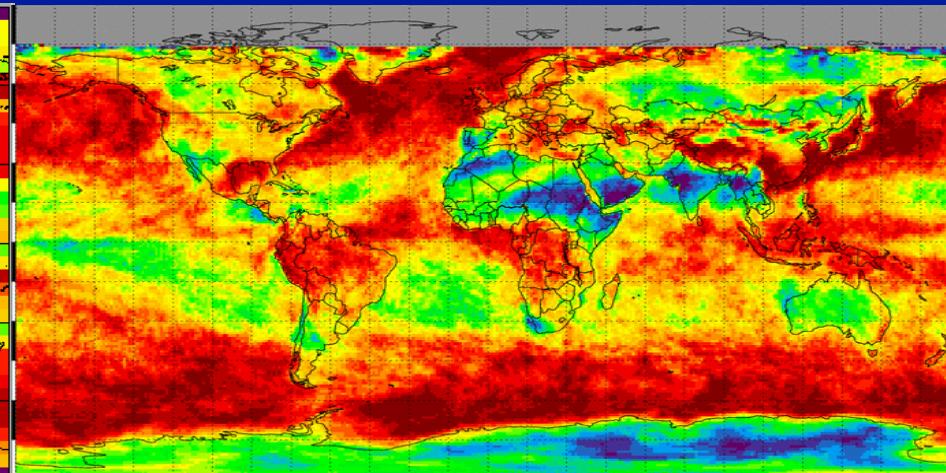
NPP



CALIPSO

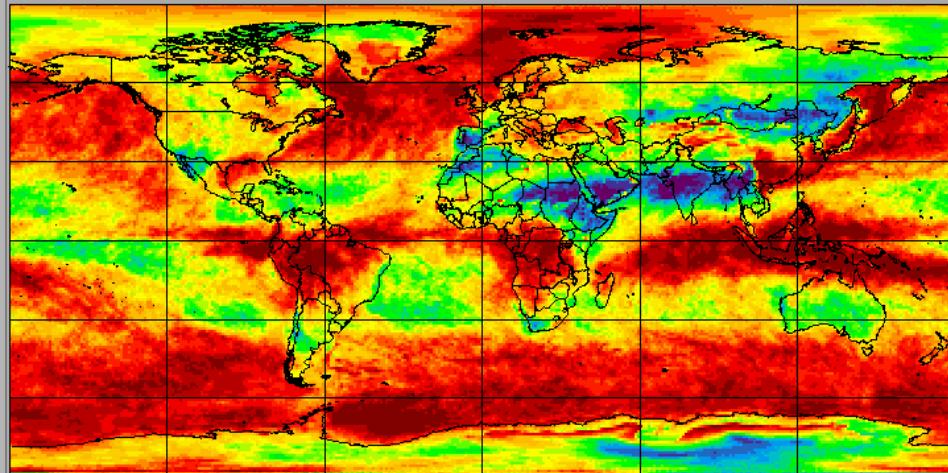


LaRC AVHRR

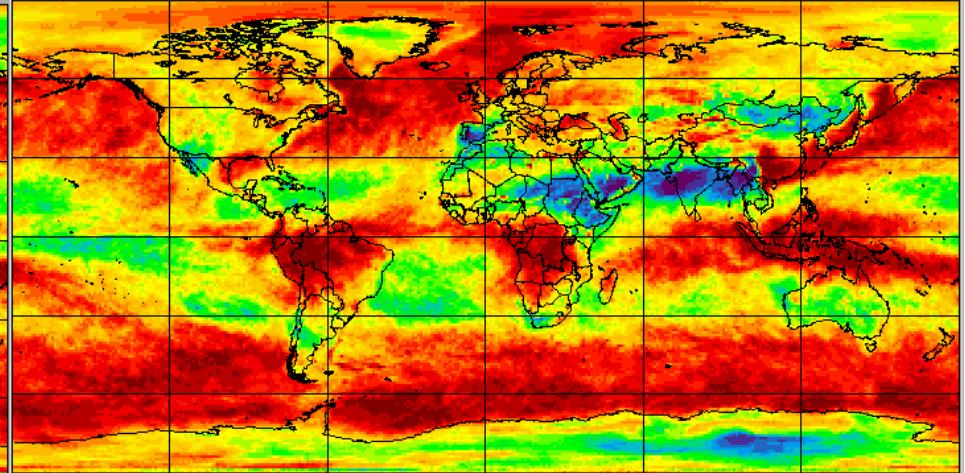


Mean Cloud Fractions, Night, February 2012

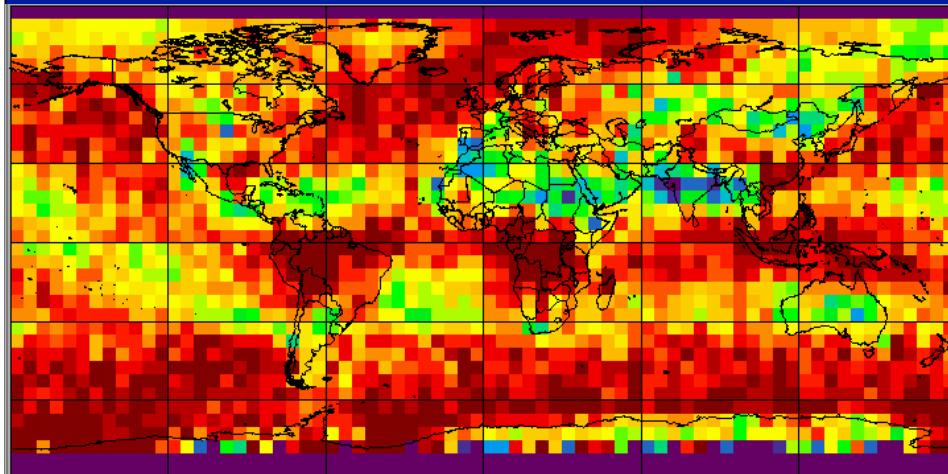
Aqua



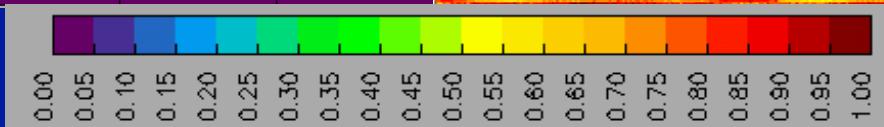
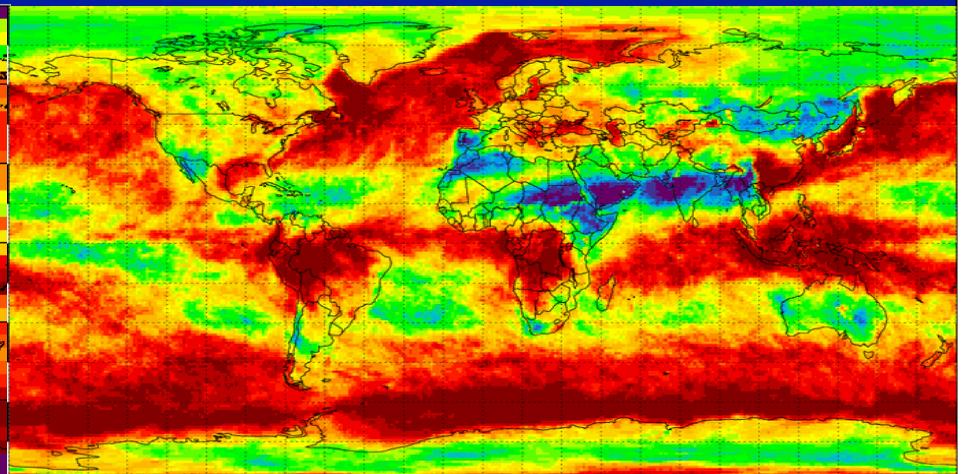
NPP



CALIPSO



LaRC AVHRR

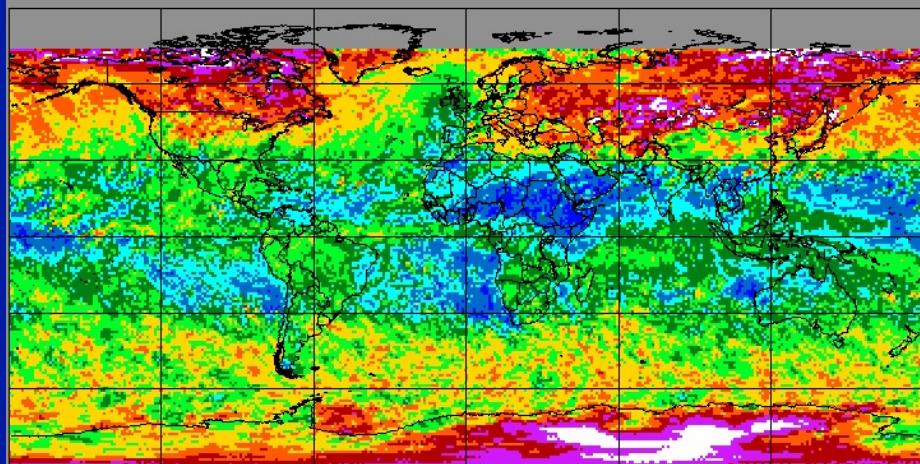


- Results are similar for all satellites except for Arctic

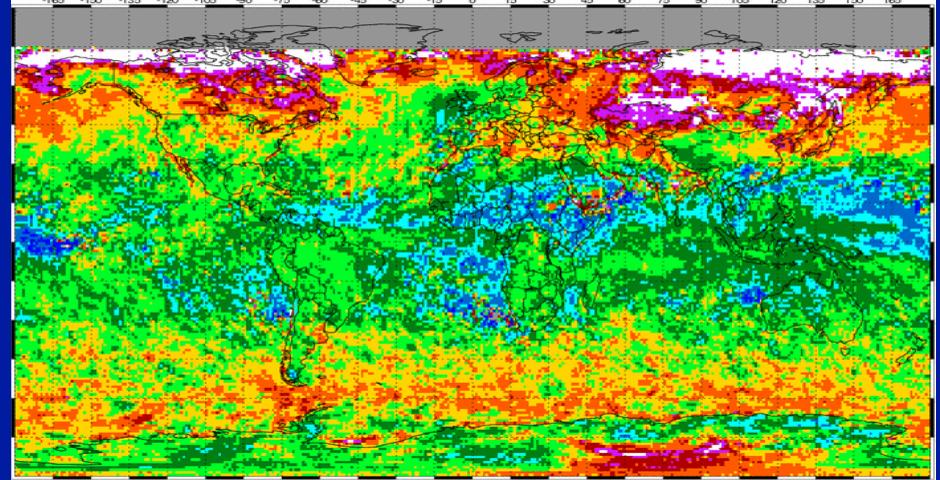


Mean Ice Cloud Re (μm), Day, February 2012

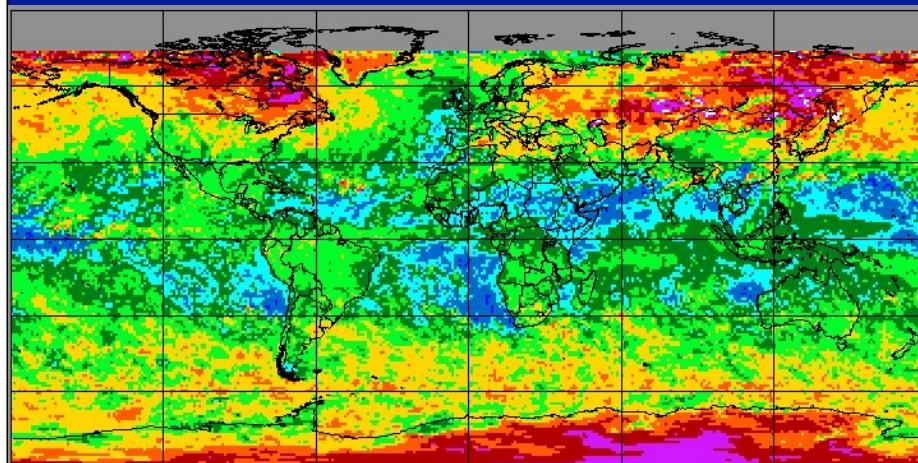
Aqua



LaRC AVHRR



NPP

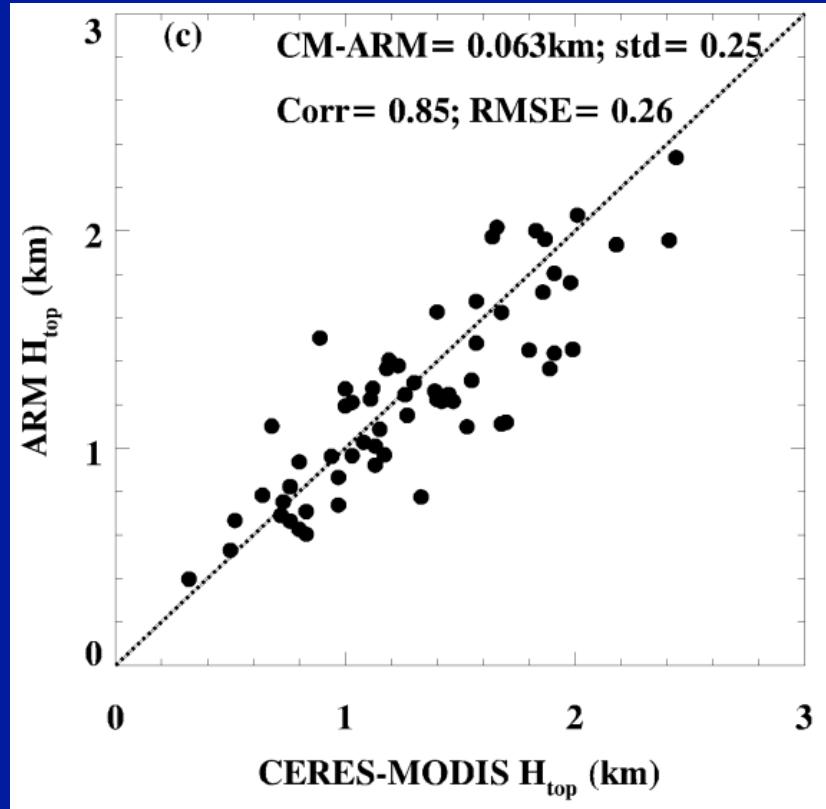


- General patterns and magnitudes of Re very similar among the 3 retrievals.
- AVHRR lacks 1.24- μm for snow/ice scenes with clouds => no thin tau

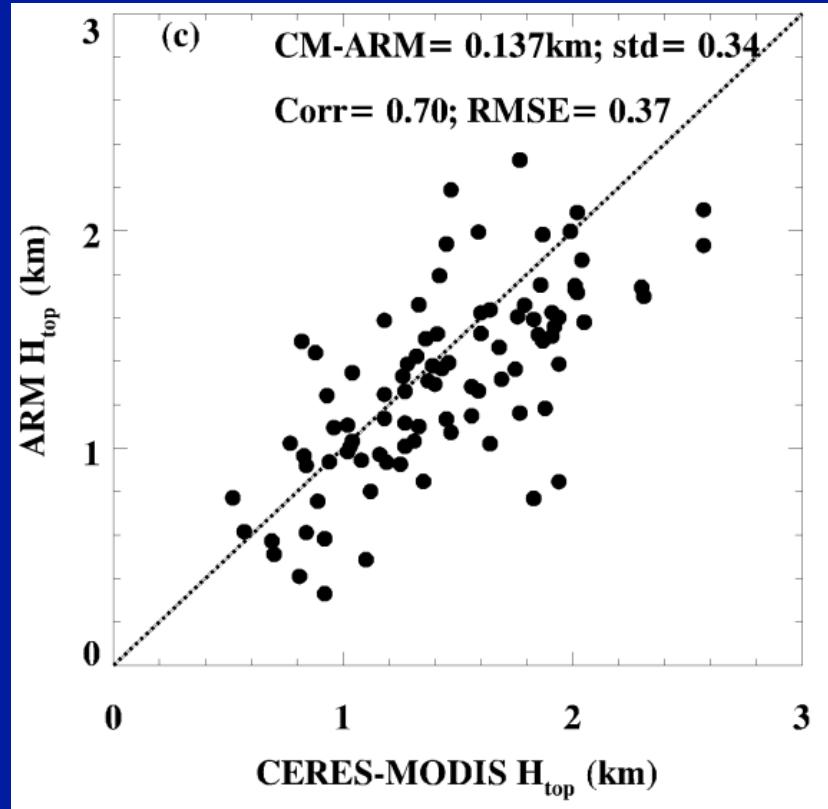


Comparison of Cloud Top Heights over Graciosa Island, Azores Aqua vs. ARM site, 2009-2010, SL Overcast only

Day



Night



- Differences similar to those from CALIPSO comparisons over ocean, except that std dev of differences is much smaller
 - probably due to OC requirement

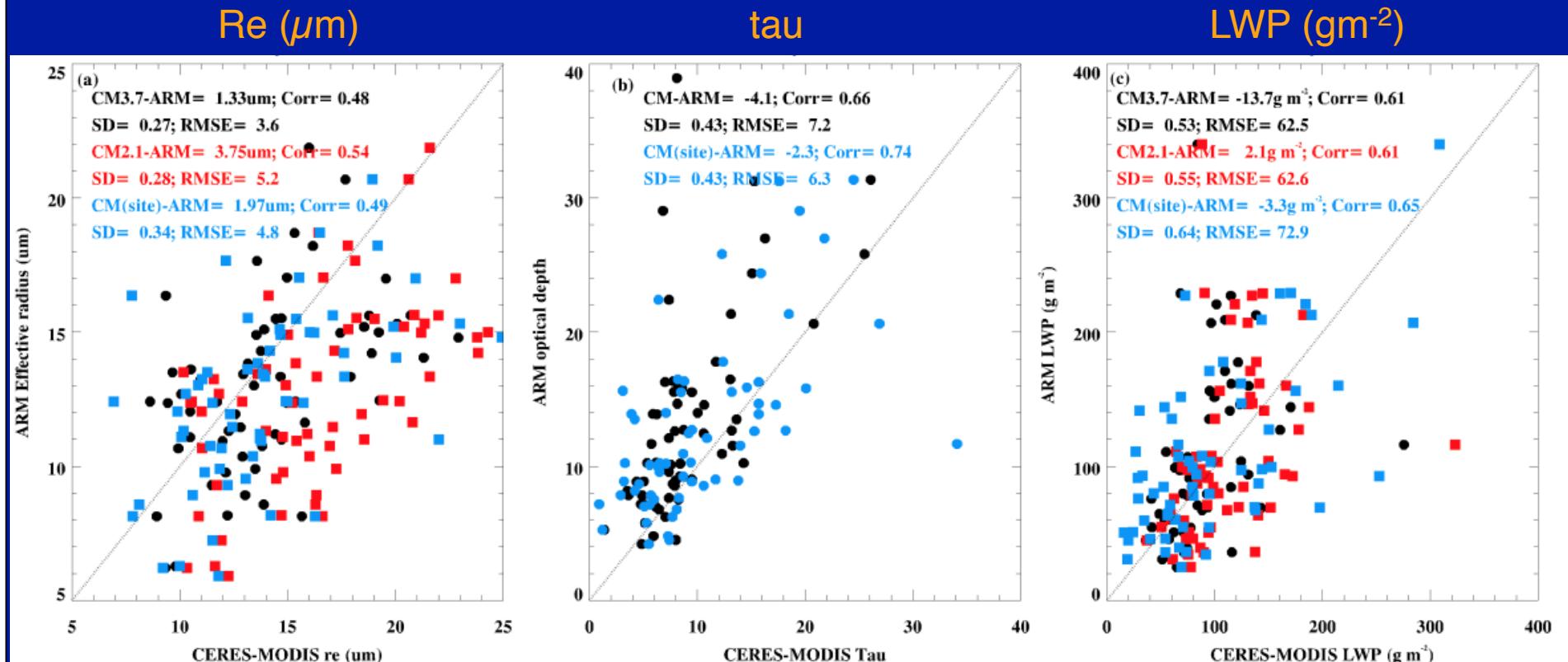


Xi et al., JGR, 2014



Comparison of Cloud Parameters over Graciosa Island, Azores

Aqua vs. ARM site, 2009-2010



- Best agreement found using only pixels nearest site because of possible island effects



Xi et al., JGR, 2014



Summary

- Aqua cloud mask gets it right 90% of the time, tradeoffs for misclassified pixels=> only small bias in cloud fraction wrt CALIPSO
 - VIIRS Ed1 nearly identical: more clouds in tropics, fewer in Arctic
 - polar night is the big difference*
- Aqua and VIIRS cloud phase very similar, but VIIRS tends to detect fewer water clouds in polar night - *any remedy for this in next Edition*
- VIIRS cloud heights: 0.15 km (water) > Aqua, 0.4 km (ice) > Aqua
 - *if true Ztop desired, use thick ice correction for MODIS Ed4*
 - *thin ice cloud heights too low in day: need lower tau*
- VIIRS optical depths > Aqua, especially in polar regions
 - *thin ice cloud tau ~0.6 of CALIPSO value => need new ice models*
- VIIRS Re(liq) < Aqua, Re(ice) ~ Aqua => LWP & IWP > Aqua
 - *may need adiabatic formula for LWP*
- VIIRS ML clouds < Aqua, mainly in storm tracks => *UL Ztop higher, tau lower*
- Validation efforts lend confidence to the results



Future

- Refine VIIRS polar night mask
- Work with SARB & TISA to improve TOA flux consistency
 - *what parameters to use from SSF? Peff? Ptop?*
 - *what IWC profiles to use in OLR computations?*
- Quantify uncertainties and try to understand 1.24- μm and 1.6/2.1- μm retrievals
 - *provide correction method? Wait for Ed5?*
- Continue working with P Yang to test & implement 2-habit ice crystal model
 - *initial tests reveal some potential formatting errors*
- Continue validation efforts
 - *Ztop in all clouds*
 - *tau, IWP, LWP in thick clouds*
 - *ML clouds!!*
 - *clouds over snow (ARM, Greenland, ARISE)*
- Document Ed4 & NPP Ed1

